PB82-103870

Restoring Hazardous Spill-Damaged Areas Technique Identification/Assessment

Atlantic Research Corp.
Alexandria, VA

Prepared for

Municipal Environmental Research Lab.
Cincinnati, OH

Sep 81

U.S. Department of Commerce
National Technical Information Service
NTIS

EPA-600/2-81-208
September 1981

PB82-103870

RESTORING HAZARDOUS SPILL-DAMAGED AREAS
Technique Identification/Assessment

by

Randall S. Wentsel
Roberta H. Foutch
William E. Harward, III
William E. Jones, III
Judith F. Kitchens
Atlantic Research Corporation
Alexandria, Virginia 22314

Contract No. 68-03-2648

Project Officer

John Brugger
Oil and Hazardous Materials Spills Branch
Municipal Environmental Research Laboratory - Cincinnati
Edison, New Jersey 08837

MUNICIPAL ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA 22161

NOTICE

THIS DOCUMENT HAS BEEN REPRODUCED FROM THE BEST COPY FURNISHED US BY THE SPONSORING AGENCY. ALTHOUGH IT IS RECOGNIZED THAT CERTAIN PORTIONS ARE ILLEGIBLE, IT IS BEING RELEASED IN THE INTEREST OF MAKING AVAILABLE AS MUCH INFORMATION AS POSSIBLE.

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/2-81- 208	2. ORD Report	3. RECIPIENT'S ACCESSION NO. PB82 103870
4. TITLE AND SUBTITLE Restoring Hazardous Spill-Damaged Areas Technique Identification/Assessment		5. REPORT DATE September 1981
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) R.S. Wentsel, R.H. Foutch, W.E. Harward, III, W.E. Jones, III and J.F. Kitchens		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Atlantic Research Corporation 5390 Cherokee Avenue Alexandria, Virginia 22314		10. PROGRAM ELEMENT NO. AZB1B
		11. CONTRACT/GRANT NO. Contract No. 68-03-2648
12. SPONSORING AGENCY NAME AND ADDRESS Municipal Environmental Research Laboratory- Cin., OH Office of Research and Development U.S. Environmental Protection Agency Cincinnati, OH 45268		13. TYPE OF REPORT AND PERIOD COVERED Final
		14. SPONSORING AGENCY CODE EPA/600/14

15. SUPPLEMENTARY NOTES
Project Officer: John E. Brugger (201)321-6634

16. ABSTRACT The goal of this study was to identify and assess methods that could be used to accelerate the restoration of lands damaged by spills of hazardous materials. The literature was reviewed to determine what response methods had been used in the past to clean up spills on land and identify other techniques that could be developed for detoxification of hazardous, spill-damaged lands.

Four biological techniques were evaluated for accelerating the restoration of spill-damaged lands in the laboratory for Phase II. The techniques and the chemicals used were the following:

I.	Enhancement of microbial degradation by indigenous organisms	chlorobenzene, Ethion
II.	Addition of mixed microorganisms from primary sewage	formaldehyde, aniline
III.	Addition of adapted/mutant microbial cultures	dinitrophenol,chlordane
IV.	Selective absorption by harvestable plants	lead, cadmium

The accelerated removal of one or both chemicals was observed in techniques II, III, and IV. The effects of the spilled chemical on the soil chemistry and microorganisms were also monitored.

In Phase III, a plan for field testing of techniques II and IV was designed. Recommended land restoration methods for spills of the 271 hazardous chemicals listed in the Federal Register (1978) were also compiled in Phase IV.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
biodegradation hazardous chemicals land restoration chemical spills	land restoration hazardous spills: chlorobenzene dinitrophenol, ethion, chlordane, formaldehyde cadmium, lead, aniline	13B

18. DISTRIBUTION STATEMENT Distribution Unlimited	19. SECURITY CLASS *(This Report)* UNCLASSIFIED	21
	20. SECURITY CLASS *(This page)* UNCLASSIFIED	22. PRICE

EPA Form 2220-1 (9-73)

BEGIN FIRST LINE OF TEXT HERE

TYPING GUIDE SHEET

CENTER OF PAGE

TOP OF IMAGE AREA

DROPPED HEAD: BEGIN SECTIONS HERE

DISCLAIMER

This report has been reviewed by the Municipal Environmental Research Laboratory, U.S. Environmental Protection Agency, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the U.S. Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

6-1/2"

9-1/8"

BOTTOM OF IMAGE AREA, OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS

BEGIN LAST LINE OF TEXT

3/8"

PAGE NUMBER

EPA-287 (Cin.)
(4-76)

BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD; BEGIN SECTIONS HERE

FOREWORD

The U.S. Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimonies to the deterioration of our natural environment. The complexity of that environment and the interplay of its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution; it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems to prevent, treat, and manage wastewater and solid hazardous waste pollutant discharges from municipal and community sources, to preserve and treat public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research and provides a most vital communications link between the researcher and the user community.

This report presents the results of an investigation of four techniques for accelerating the natural recovery of hazardous chemical spill-damaged land. Three of the techniques involve the use of microorganisms to decompose the hazardous chemical; a fourth technique utilizes plants to bioaccumulate heavy metal compounds. The report will be of interest to all those involved with spill cleanup and soil biology.

Francis T. Mayo, Director
Municipal Environmental Research
Laboratory

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA, OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 247)
PAGE NUMBER
U.S. GOVERNMENT PRINTING OFFICE 1980
TYPING GUIDE SHEET

BEGIN FIRST LINE OF TEXT HERE
TYPING GUIDE SHEET
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD; BEGIN SECTIONS HERE

ABSTRACT

This study identifies and assesses methods for accelerating the restoration of lands damaged by spills of hazardous materials. The first phase of the study involved a literature review to determine what response methods had been used in the past to clear up spills on land and to identify other techniques that could be developed for detoxification of hazardous spill damaged lands.

Four primarily biological techniques for accelerating the restoration of spill-damged lands were evaluated in the laboratory during the second phase of the study. The techniques and the chemicals used were the following:

	Technique	Chemical
I.	Enhancement of microbial degradation by indigenous organisms	chlorobenzene Ethion
II.	Addition of mixed microorganisms from primary sewage effluent	formaldehyde aniline
III.	Addition of adapted/mutant microbial cultures	dinitrophenol chlordane
IV.	Selective absorption by harvestable plants	lead nitrate cadmium nitrate

The accelerated removal of one or both chemicals was observed in techniques II, III, and IV. The effects of the spilled chemical on the soil chemistry and microorganisms were also monitored.

During the third phase, a plan for field testing of techniques II and IV was designed. Recommended land restoration methods for spills of the 271 hazardous chemicals listed in the Federal Register (1978) were compiled during the fourth phase.

This report was submitted in partial fulfillment of Contract No. 68-03-2648 by Atlantic Research Corporation under subcontract to Rockwell International Corporation, Environmental Monitoring & Services Center, Newbury Park, California, under the sponsorship of the U.S. Environmental Protection Agency. This report covers the period 7 February 1979 to 1 August 1980, and work was completed as of 15 December 1980.

6-1/2"
9-1/8"
BEGIN LAST LINE OF TEXT
TTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

BEGIN FIRST LINE OF TEXT HERE
TYPING GUIDE SHEET
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD, BEGIN SECTIONS HERE

CONTENTS

Foreword iii
Abstract iv
Figures vii
Tables xi
Abbreviations and Symbols xv
Acknowledgment xvii

1. Introduction 1
2. Conclusions 3
3. Recommendations 6
4. Literature Review of Hazardous Spills on Land and Restoration Methods Employed 7
    Identification of Hazardous Spills on Land 7
    PCB Spill, Kingston, Tennessee 13
    Acrylonitrile Spill, Leon, Kentucky 23
    Phenol Spill, Slabtown, Maryland. 37
    Acrylonitrile Spill, Dayton, Ohio 47
    Nitric Acid Spill, Estill, South Carolina 52
    Caustic Soda Spill, Duffee, Mississippe 55
    Formalin Spill, Rensselaer County, New York 57
    Toluene Spill, Wallsburg, Utah 70
    Arsenic Trioxide Spill, Elkhorn, Wisconsin 70
    Conclusions on Land Restoration Methods 79
5. Fate of Hazardous Material Spills on Land and Potential Restoration Methods 81
    Fate of Hazardous Materials Spilled in the Environment. . 81
    Restoration of Spill-Damaged Lands: Previously . . . 81
      Used Techniques 81
6. Selection of Chemicals for Evaluation of Land Restoration Techniques 116
7. Experimental Methodology 118
    Environmental Chamber Construction 118
    Chemical Spills in Environmental Chambers 121
    Land Restoration Techniques 124
    Sampling Methodology 127
    Analytical Procedures 127
8. Experimental Results 135
    Introduction 135
    Land Restoration Technique I - Monochlorobenzene Spill. . 135
    Land Restoration Technique I - Ethion Spill 144
    Land Restoration Technique II - Formaldehyde Spill . . . 159
    Land Restoration Technique II - Aniline Spill 170

BOTTOM OF IMAGE AREA, OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
BEGIN LAST LINE OF TEXT
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

CONTENTS (continued)

Land Restoration Technique III - Chlordane Spill 179
Land Restoration Technique III - 2,4-Dinitrophenol Spill . 184
Land Restoration Technique IV - Cadmium Nitrate and Lead Nitrate Spill 188
9. Evaluation of the Land Restoration Techniques 194
10. Field Demonstration Test Design 196
Site Selection and Pretest Preparation - Task I 196
Land Restoration After a Formaldehyde Spill - Task II. . . 197
Land Restoration After an Aniline Spill - Task III 202
Land Restoration After a Spill of Cadmium Nitrate - Task IV 203
11. Operating Procedures for Restoration of Spill-Damaged Lands . . 204
Assessing the Damage to the Land 223
Selection of the Appropriate Land Restoration Technique. . 223
Application of the Land Restoration Technique. 223

References 229

Appendices

A. Background Data on Hazardous Chemicals Used in Laboratory Tests . 235
B. Monochlorobenzene Data 252
C. Ethion Data 269
D. Formaldehyde Data 298
E. Aniline Data 321
F. Chlordane Data 343
G. 2,4-Dinitrophenol Data 348
H. Cadmium Nitrate and Lead Nitrate Data 353

EPA-287 (Cin.)
(4-76)

BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD; BEGIN SECTIONS HERE

FIGURES

Number		Page
1	Topography of Spill Site, Kingston, Tennessee.	15
2	Temperature of Three Soil Types with Depth, Kingston, Tennessee.	19
3	Solvent Concentration Profile - Well Located Closest to PCB Spill Site	22
4	Acrylonitrile Spill Near Leon, Kentucky - Topography of Area	29
5	Spill Site Shortly After Derailment.	30
6	Numbered Soil Sampling Locations in Spill Area (a and b)	33
7	Topography of Phenol Spill Area, Slabtown, Maryland.	39
8	Detailed Map of Phenol Spill Site and Sampling Location.	40
9	Topography of Acrylonitrile Spill Area, Dayton, Ohio	49
10	Detailed Map of Spill Site	51
11	Topography of Nitric Acid Spill Site, Estill, South Carolina	54
12	Topography of Caustic Soda Spill Site, Duffee, Mississippi	59
13	Topography of Formaldehyde Spill Site, Rensselaer County, New York	63
14	Spill Area and Sampling Stations	67
15	Topography of Toluene Spill Area, Wallsburg, Utah.	72
16	Topography of Arsenic Trioxide Spill Site, Elkhorn, Wisconsin. . . .	75
17	Disappearance of Malaoxon in Sterile and Non-Sterile Soil Samples at pH 6.2, 7.2 and 8.2	90
18	Disappearance of Malathion in Sterile and Non-Sterile Soil Samples at pH 7.2.	91

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA, OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 287)
☆ U.S. GOVERNMENT PRINTING OFFICE 1980-660-839
TYPING GUIDE SHEET

FIGURES (continued)

19 Effect of the Level of Crude Oil Addition to the Soil in the Germination of Maize Grains 104

20 Diagram of Trace-Metal Cycling in a Plant-Environmental System 105

21 Dose-Response Curves of Seedling Lettuce Subjected to Acute Zinc and Copper Toxicity. 106

22 Set of Three Environmental Chambers 119

23 Environmental Chambers. 120

24 Water-Cooled Condenser, Carbon Filter and Sodium Hydroxide Bubbler from Spill Chamber. 120

25 Experimental Design for Plant Uptake Studies. 122

26 Upper-Level Organic Soil Microbial Populations - Monochlorobenzene Spill 137

27 Upper-Level Sandy Soil Microbial Population - Monochlorobenzene Spill 138

28 Upper-Level Clay Soil Microbial Population - Monochlorobenzene Spill 139

29 Monochlorobenzene Concentrations in the Organic Soils 141

30 Monochlorobenzene Concentrations in the Sandy Soils 142

31 Monochlorobenzene Concentrations in the Clay Soils 143

32 Upper-Level Organic Soil Microbial Populations - Ethion Spill . . . 146

33 Upper-Level Sandy Soil Microbial Populations - Ethion Spill 150

34 Upper-Level Clay Soil Microbial Populations - Ethion Spill. 152

35 Upper-Level Ethion Concentrations in Organic Soil 154

FIGURES (continued)

36 Upper-Level Ethion Concentrations in Sandy Soil 155

37 Upper-Level Ethion Concentrations in Clay Soil 156

38 Upper-Level Organic Soil Microbial Populations - Formaldehyde Spill 160

39 Upper Level Sandy Soil Microbial Populations - Formaldehyde Spill 161

40 Upper-Level Clay Soil Microbial Populations - Formaldehyde Spill 162

41 Formaldehyde Concentrations in Upper Layer of Organic Soils 166

42 Formaldehyde Concentrations in Upper Layer of Sandy Soils 167

43 Formaldehyde Concentrations in Upper Layer of Clay Soils. 168

44 Upper-Level Organic Soil Bacterial Populations - Aniline Spill. . . 172

45 Upper-Level Sandy Soil Bacterial Populations - Aniline Spill. . . . 173

46 Upper-Level Clay Soil Bacterial Populations - Aniline Spill 174

47 Aniline Concentrations - Upper Level of Organic Soil. 175

48 Aniline Concentrations - Upper Level of Sandy Soil. 176

49 Aniline Concentrations - Upper Level of Clay Soil 177

50 Chlordane Concentrations in Upper Level of Organic Soil 180

51 Chlordane Concentrations in Upper Level of Sandy Soil 181

52 Chlordane Concentrations in Upper Level of Clay Soil 182

53 2,4-Dinitrophenol Concentrations in the Upper Level of the Organic Soils 185

BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD: BEGIN SECTIONS HERE
BEGIN LAST LINE OF TEXT
3/8"
PAGE NUMBER
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
EPA Form 2350-4 (4-80)
(PREVIOUSLY EIN, EPA FORM 257)
U.S. GOVERNMENT PRINTING OFFICE: 1980-660-638
TYPING GUIDE SHEET

FIGURES (continued)

54 Dinitrophenol Concentrations in the Upper Level of the Sandy Soils 186

55 Dinitrophenol Concentrations in the Upper Level of the Clay Soils 187

56 Test Plot Design 198

57 Logic Tree for Selection of Appropriate Restoration Techniques . . . 224

TABLES

Number Page

1 Land Spills of the 271 Hazardous Chemicals 1975-1977. 8

2 Background of PCB Spill, Kingston, Tennessee. 14

3 Weather Conditions-Kingston, Tennesse, Area 16

4 Monthly Precipitation Levels from 1973-1975 at PCB Spill Area 17

5 Comparison of Analytical Data from Core Samples Collected in in 1973 and 1975 20

6 Microbial Populations Relative to pH of Soil Samples 24

7 Microbial Populations Relative to Moisture Content of Soils 25

8 Microbial Populations Relative to Soil Types. 26

9 Microbial Populations Relative to PCB Concentration in Core Samples 27

10 Background of Acrylonitrile Spill, Near Leon, Kentucky. 28

11 Weather Conditions, Leon, Kentucky. 32

12 Acrylonitrile Levels in Surface Soil Samples. 35

13 Acrylonitrile Levels in Soil Cores. 36

14 Background of Phenol Spill, Slabtown, Maryland. 38

15 Weather Conditions of Slabtown, Maryland. 41

16 Weather Conditions After the Spill in Slabtown, Maryland. 42

17 Phenol Levels Through Treatment System and Jennings Run 44

18 Phenol Levels in Soil Samples 46

19 Background of Acrylonitrile Spill, Dayton, Ohio 48

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN-EPA FORM 237)

TYPING GUIDE SHEET

TABLES (continued)

20 Weather Conditions, Dayton, Ohio 50

21 Background of Caustic Soda Spill, Estill, South Carolina 53

22 Weather Conditions, Estill, South Carolina 56

23 Background of Caustic Soda Spill, Duffee, Mississippi 58

24 Weather Conditions, Duffee, Mississippi 60

25 Soil pH levels After Treatment with Alum 61

26 Background of Formalin Spill, Rensselaer County, New York 62

27 Weather Conditions - Rensselaer, New York. 65

28 Weather Conditions After Spill 66

29 Formaldehyde Levels in the Soil Samples. 68

30 Formaldehyde Levels in Marsh Soil and Water Samples. 69

31 Background on Toluene Spill, Wallsburgh, Utah. 71

32 Weather Conditions, Wallsburh, Utah. 73

33 Background of Arsenic Trioxide Spill, Elkhorn, Wisconsin 74

34 Weather Conditions, Elkhorn, Wisconsin 76

35 Weather Conditions After the Spill 78

36 Treatment Methods for Hazardous Material Spills. 80

37 Microorganisms Reported to Degrade Pesticides 84

38 Types of Pesticide Transformation in Soil and/or Plants. 86

39 Percentage of Chemical and Microbial Degradation of Malathion in Soil After 10 Days 88

TABLES (continued)

40 Insecticide Absorption by Sweet Potatoes and White Potatoes from Treated Soil 94

41 Persistence of Pesticides in Soil 97

42 Biodegradation of ^{14}C-carboxyl EDTA in a Variety of Soils 98

43 Effect of Various Fungicide Treatments on Seed Germination Seedling Injury and Chromosome Abberations in Barley 100

44 The Types and Frequency of Chromosomal Abberations Produced by a 30 min. Treatment with Various Fungicides in the Secondary Roots of Vicia Faba 102

45 Typical Distribution Among Plant Parts of Phaseolus Vulgaris L. of Some Trace Metals 107

46 Forage Yields and Uptake of Phosphorus and Heavy Metals by Corn as Affected by Soil pH and Inclusion of Heavy Metals in Reagent-Grade Diammonium Phosphate. 109

47 Total Yield and Concentrations of Heavy Metals in Vegetables, as Affected by Sludge Treatment 110

48 Upper-Layer Fungal Counts - Ethion Spill. 147

49 Ethion Related Residues 158

50 Upper-Layer Fungal Counts - Formaldehyde Spill. 163

51 Rate of Formaldehyde Loss 170

52 Loss Rate of C-14 Activity. 170

53 Half-Lives of Aniline in Organic and Sandy Soils. 178

54 14 Radiation Counts in Sandy Soils Treated with ^{14}C Chlordane 183

55 Average Soil Concentrations of Cadmium and Lead 189

BEGIN FIRST LINE OF TEXT HERE
TYPING GUIDE SHEET
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD; BEGIN SECTIONS HERE

TABLES (continued)

56 Lead Levels in Plants as a Function of Soil Type and Treatment. . . 190

57 Cadmium Levels in Plants as a Function of Soil Type and Treatment 191

58 ANOVA: Latin Square Design 200

59 ANOVA: Factorial Experiment with Blocking 201

60 ANOVA: Two-Way Analysis 201

61 Hazardous Chemical Classification and Applicable Restoration Techniques 205

62 Vegetation Recommendations to Cover Land Contaminated With Hazardous Materials. 228

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

ABBREVIATIONS AND SYMBOLS

A - acre
$AgNO_3$ - silver nitrate
ANOVA - analysis of variance
BOD_5 - 5-day biological oxygen demand
^{14}C - radio labelled carbon
$CA (NO_3)_2$ - calcium nitrate
cc/min - cubic centimeters per minute
$Cd(NO_3)_2$ - cadmium nitrate
CEC - cation exchange capacity
cm - centimeter
CO_2 - carbon dioxide
cpm - counts per minute
COD - chemical oxygen demand
2,4,-D - (2,4-Dichlorophenoxy) acetic acid
2,4,5-T - (2,4,5-Trichlorophenoxy) acetic acid
DBCP - 1,2-Dibromo-3-Chloropropane
DDE - dichlorodiphenyldichloroethylene
DDT - 1,1,1-Trichloro-2, 2-bis (p-chlorophenyl) ethane
DNBP - 4,6-Dinitro-o-sec-butylphenol
DSMA - disodium monomethlarsonate
EDTA - ethylenediaminetetraacetic acid
$FeCl_3$ - ferric chloride
GC - gas chromatography
g - gram
g/cm^2 - gram per square centimeter
G.E. - General Electric
ha - hectare
H_3BO_3 - boric acid
ID - inner diameter
IR - infrared
kg - kilogram
KH_2PO_4 - mono potassium phosphate
K_2HPO_4 - dipotassium phosphate
KOH - potassium hydroxide
LB - pound
LC50 - concentration which kills 50% of treated population
LD50 - dose which kills 50% of treated population
LDL_o - largest dose nonlethal to treated population
m - meter
M - molar
mm Hg - millimeters of mercury
μ - micro

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD. BEGIN SECTIONS HERE

ABBREVIATIONS AND SYMBOLS (continued)

µm - micrometer
min - minute
ml - milliliter
mg/kg - milligrams per kilogram
$MgCl_2$ - magnesium chloride
mCi - millicurie
µCi - microcurie
M.A.C. - maximum allowable concentration
N_2 - nitrogen
nm - nanometer
NMR - nuclear magnetic resonance
NH_4HO_3 - ammonium nitrate
NaOH - sodium hydroxide
n.s.i. - no specific isomer
OSC - on-scene coordinator
Pa - Pascals, unit of pressure
PCB - polychlorinated biphenyl
PCP - pentachlorophenol
pH - measure of acidity or basicity
PMA - acetoxyphenylmercury
ppb - parts per billion
ppm - parts per million
RTV - room temperature vulcanizing silicone rubber
sp. - species
torr - unit of pressure = mm Hg ($0^{o}C$)
TLV - threshold limit value
TLm - median tolerance limit
txs - treatment-sampling time interaction
<,> - less than, more than

ABBREVIATIONS FOR TABLE 61

s - water soluble to the extent of greater than 50 ppm
i - water insoluble less than 50 ppm
b - biodegradable with incomplete mineralization and a half-life in soil (actual or predicted) of less than 4 months
r - chemically or photochemically reactive
t - biotransformed organic
u - biouseable inorganic
v - volatile from soil due to high vapor pressure, codistillation with water, water insolubility
p - persistent toxic residue
n - persistent non-toxic residue

BOTTOM OF IMAGE AREA, OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
BEGIN LAST LINE OF TEXT
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD: BEGIN SECTIONS HERE

ACKNOWLEDGMENT

This work was performed under subcontract to the Environmental Monitoring & Services Center of Rockwell International, Newbury Park, California. The authors wish to thank George R. Schneider, Project Manager, Environmental Monitoring & Services Center, and John E. Brugger, Project Officer, U.S. Environmental Protection Agency, for their direction and support.

6-1/2"
9-1/8"
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

SECTION 1

INTRODUCTION

The spill of a hazardous chemical on land can produce long-term damage to the area affected. The plants and organisms exposed to concentrated doses of a chemical will usually be eradicated from the spill area for some time. Natural recovery of spill damaged land is a slow process that can take years. In addition, if erosion or leaching of nutrients from the area occurs, the land can become permanently scarred. If the chemical leaches into the groundwater, an entire watershed can become contaminated.

The rapid restoration of chemically damaged land will reduce the danger of further contamination and prevent the land from being permanently affected.

The present study focused on the identification and development of biological techniques which have the potential for restoration of spill damaged lands and a laboratory assessment of the feasibility of these techniques. A literature search was conducted to determine the current biological, chemical and physical techniques used to treat spill damaged land. Viable biological techniques were then identified and four were selected for laboratory evaluation.

The first technique studied was the enhancement of microbial degradation by indigenous organisms. This technique was tested for several reasons. First, the microorganisms which have survived the initial shock from the spilled chemical are relatively resistant to the chemical. If the surviving microbial population can be increased rapidly with the addition of nutrients, then they may be able to degrade the chemical. Also, the organisms used are from the spill area and do not have to be specially cultured.

The second technique evaluated the use of microorganisms in primary sewage effluent to degrade a spilled chemical. Primary sewage effluent has a variety of microorganisms present in it and the effluent is usually high in nutrients. Primary sewage effluent can be used to replenish the microbial population in the spill area. If nutrients are added, the microorganisms from the primary sewage effluent can degrade the chemical. In addition, primary sewage effluent is cheap and readily available.

The third technique was the addition of adapted/mutant microbial cultures. For this method soil or primary sewage effluent microorganisms were cultured in nutrient medium containing the chemical to be degraded. The chemical was the sole carbon source for the organisms. After several subcultures, a culture was developed that could utilize the chemical of concern. This culture, with nutrients, can then be applied to the soil to degrade the spilled chemical.

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN: EPA FORM 287)
© U.S. GOVERNMENT PRINTING OFFICE 1980-660-639
TYPING GUIDE SHEET

The final technique evaluated was the uptake of heavy metals by harvestable plants. Plants were selected for use based on data from the literature search and preliminary tests. For the heavy metal contaminated soil, conditions for uptake by the plants were optimized by adjusting the pH and by adding a chelating agent.

A plan for field testing of the two most promising techniques from the laboratory tests was then developed. The plan included the chemicals to be spilled, restoration treatments to be applied, and sampling techniques.

Finally, recommended land restoration methods were developed for the hazardous chemicals under consideration. The chemicals were environmentally classified and restoration techniques were proposed for treatment.

EPA Form 2350-4 (4-80)
(PREVIOUSLY LIN: EPA FORM 287)
U.S. GOVERNMENT PRINTING OFFICE 1980-660-839
TYPING GUIDE SHEET

BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD; BEGIN SECTIONS HERE

SECTION 2

CONCLUSIONS

Four biological techniques were investigated for the restoration of spill-damaged lands. Three of these techniques were concerned with the use of microorganisms to degrade hazardous chemicals adsorbed in soil. The fourth technique involved terrestrial plants as a means of removing heavy metal contamination from soils by bioaccumulation. The investigations were conducted with three different types of soil, organic, sandy and clay.

The technique of using microbial populations, present in the soil at the spill site, to degrade volatile, non-water soluble, low polarity compounds, such as monochlorobenzene, was found to be ineffective. Before bacterial populations could adapt to and degrade the somewhat volatile chemical, it had evaporated from the soil.

Ethion, an organo-phosphorus pesticide, was the second chemical which tested the use of indigenous microbial populations to degrade a chemical. After the Ethion spill the microbial populations decreased. The decrease was most likely due to the suffocation of the organisms or the lower pH of the soil after the spill. The application of nutrient broth and soil pH adjustments to near neutral levels were successful in increasing the indigenous microbial populations in the treated chambers. However, the microorganisms surviving the Ethion spill were unable to attack and degrade the Ethion.

Treatments to increase the availability of Ethion to the microbial population were then conducted. The applications of Tween 80 and ethanol to the soils were expected to increase the water solubility of the Ethion. It was anticipated that the increased solubility would lead to a higher biodegradation rate. However, the Ethion concentration in the soil did not drop substantially after the treatment.

Soil pH values were then adjusted to basic levels, initially between 9 and 10 units. When this treatment proved ineffective for increasing the rate of hydrolysis of Ethion, a severe treatment using approximately 50% ethanol and 8% NaOH solution was used to chemically breakdown the Ethion. This treatment substantially reduced the Ethion levels in the organic and sandy soils, but not in clay soil. However, a treatment this severe could only be used in small spill areas under carefully controlled conditions. Once the concentration of the hazardous chemical has been reduced to tolerable levels, the soil would have to be neutralized, reseeded with a mixed population of microorganisms and revegetated.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA, OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA Form 2350-4 (4-80)
[PREVIOUSLY CIN. EPA FORM 287]
U.S. GOVERNMENT PRINTING OFFICE 1980-660-828
TYPING GUIDE SHEET

Although the technique of adding spill resistant strains of indigenous microbes with the expectation that these microbes will degrade the spilled chemical, was unsuccessful for monochlorobenzene and Ethion. The ability of soil microorganisms to degrade many of the simpler chemicals such as ammonium acetate has long been established.

In Technique II, mixed cultures of microorganisms from primary sewage effluent were evaluated for their ability to hasten the degradation of formaldehyde and aniline in various soil types.

The accelerated removal of formaldehyde from the soil by treatment of the spill damaged area with primary sewage effluent and a mixed microbial cultures containing primarily Pseudomonas sp. was moderately successful. Both treatments increased the rate of formaldehyde removal from sandy and clay soils after the second application. It appears from the data, that the treatments are useful at formaldehyde levels less than 2000 ppm. In organic soils, sufficient nutrients were available to promote residual microbial growth without reinoculating the soil. However, this recovery only happens when formaldehyde levels fall below 1000 ppm. Microbial populations generally increased to pre-spill levels when all the formaldehyde was removed from the soil.

Only small amounts of formaldehyde were found in the condenser traps or carbon filters. Radiometric analyses of the sodium hydroxide bubblers indicated that the majority of the formaldehyde was metabolized to CO_2. No residual ^{14}C was found in the soil. Thus, it appears that metabolism of the formaldehyde was performed by methylotrophic bacteria probably utilizing the alternate ribulose-5-phosphate pathway suggested by Colby and Zatman and reported in Anthony (1975).

For the aniline spill, the initial soil treatments with primary sewage effluent were ineffective in accelerating the removal of aniline from the soil. However, enhanced degradation of aniline was achieved when a mixed microbial culture, grown in the presence of aniline with nutrient salts and yeast extract, was added to the soil. The addition of the mixed culture increased the rate of disappearance of aniline from the organic and sandy soil treated chambers.

The use of adapted microbial cultures to degrade the environmentally persistent compounds, chlordane and dinitrobenzene in situ, were studied as the third land restoration method. Due to contract time constraints, these chemicals were only monitored for 49-62 days after the spill. In the chlordane spill, significant $^{14}CO_2$ levels were not detected in NaOH bubblers indicating that cleavage of the rings did not occur. However, some loss of chlordane was observed in some of the treated chambers. The data on the dinitrophenol spill indicated that some increase in the rate of disappearance of dinitrophenol did occur in the organic and clay soils treated with adapted microbial cultures. However, since this compound was not radiolabelled, it is uncertain if the disappearance was due to the biodegradation or simply biotransformation of the compound.

The uptake of cadmium and lead from the soil by plants was evaluated in Technique IV. The results indicated that the plants concentrated the highest amount of metal from the soils which received a chelating agent, disodium EDTA. The plants also concentrated cadmium to a greater extent than lead.

BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD; BEGIN SECTIONS HERE
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
PAGE NUMBER
EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 227)
U.S. GOVERNMENT PRINTING OFFICE
TYPING GUIDE SHEET

The data indicate that uptake of metals by plants can provide an effective method of removing the metals from the soil. Proper soil conditions must be maintained to aid the uptake, e.g., acidic pH and the presence of a chelating agent. In addition, at least several harvests of the plants would have to be conducted. Although not evaluated in this study, plant uptake of certain persistent organics from the soil should also be feasible.

The accelerated removal of formaldehyde and aniline from the soils in Technique II and the uptake of cadmium by the plants were the most successful results. These techniques should be further evaluated for the chemical tested and possibly expanded to other hazardous chemical classes.

EPA Form 2350-8 (4-80)
(PREVIOUSLY CIN EPA FORM 287)
U.S. GOVERNMENT PRINTING OFFICE
TYPING GUIDE SHEET

SECTION 3

RECOMMENDATIONS

The treatment of hazardous spill-damaged lands cannot be effective until laws are enacted to require the reporting of all significant spills of all hazardous materials. Currently, partial reporting of spills to the U.S. EPA, state EPA and other state agencies occurs. The Department of Transportation also receives spill reports, but these may be delivered months after the spill occurs. No one group has complete records on the magnitude of hazardous material spills on land.

Once a coordinated communication system is developed, recommended procedures for the treatment of chemicals or classes of chemicals should be developed more completely. Manufacturers, shippers, state and federal agencies should meet for an exchange of information and cooperation in the treatment of spills. Areas where information is lacking could be identified and goals formulated.

Future research and development efforts on restoration of spill damaged lands should concentrate on the following areas:

- demonstration of in situ biodegradation of chemicals that can easily be degraded by microbes and preparation of a detailed guide for the application of this technology by the on-site spill response coordinator
- demonstration of vegetative uptake of metals from the soil and preparation of a detailed guide for the application of this technique to actual spill situations
- research on the uptake of persistent organics by plants
- research into adapted/mutant or genetically engineered microorganisms to degrade specific environmentally persistent chemicals such as the polyhalogenated organics
- research on the application of photochemical degradation to a land spill of persistent polyhalogenated organics

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 237)
TYPING GUIDE SHEET

SECTION 4

LITERATURE REVIEW OF HAZARDOUS SPILLS ON LAND AND RESTORATION METHODS EMPLOYED

IDENTIFICATION OF HAZARDOUS SPILLS ON LAND

Under Pl-95-500, it is not mandatory to report hazardous spills on land when surface water is not threatened. As a result, the data on spills of hazardous materials on land are limited. However, the Office of Hazardous Materials of the Department of Transportation (DOT) maintains computer files and reports on hazardous material spills occurring during transit. These files were examined for the years 1971-1978 to identify large spills of hazardous materials on land. Computer printouts contained information on the commodity or chemical spilled, locations of the spill, shipper and cause of the spill. Reports concerning spills of the 271 hazardous substances listed in Federal Register, Vol. 43 (49), p. 10474, were then evaluated by the following criteria:

- size of the spill
- locations of the spill
- methods used for clean-up

A partial list of spill reports which were selected for further analysis is presented in Table 1. During the evaluation, it was noted that large, common spills were mainly acids and bases. Smaller spills of unusual chemicals, such as styrene monomer, were also examined.

The U.S. EPA Regional Offices spill response units having jurisdiction for each spill were contacted for additional information. Reports on the actions taken by the U.S. EPA or the names of responsible individuals at the state level were obtained. A large number of spills reported to DOT were not reported to, or received no action from the U.S. EPA. State and local agencies contacted for information on the spills included the state EPA, Department of Natural Resources, Department of Agriculture, State Police, the County Sheriff, and state laboratories. Reports on the response to the spills, chemical data, and other pertinent information were received. Many spills had received no response at the state level or little information was available on the spills. Other sources were contacted for general and specific information on the spills. These sources included shippers, carriers, contracted laboratories, Chemtrec (on-line emergency chemical information system) and the EPA data base (OHM-TADS).

A final group of spills was selected for detailed analysis. They were chosen based on the chemical spilled, the information available, location, and

TABLE 1. LAND SPILLS OF THE 271 HAZARDOUS CHEMICALS 1971-1977

State/City	Date	Chemical	Amount Spilled	How Spilled
AL Wilcox	5/11/76	Aniline Oil	11,356 liters	derailment
AZ Peridot	5/20/77	Sulphuric Acid	11,848 kg	accident
AR Spadra	1/08/76	Acetic Anhydride	283,906 liters	derailment
AR Waveland	7/02/78	Cyclohexane	68,137 liters	derailment
AR Pine Bluff	2/03/77	Caustic Potash	Tank car	rupture
CA LaMirada	5/08/78	Vinyl Acetate	3,785 liters	rail leak
CA Pinole	8/04/78	Sodium Hydroxide	101,070. liters	accident
CA Union City	1/25/77	Calcium Hypochlorite	317 kg	leak
CA Los Angeles	11/08/77	Ferric Chloride	83 drums	leak
CO Steamboat Springs	10/21/77	Anhydrous Ammonia	2,041 kg	accident
FL Balm	7/07/77	Phosphoric Acid	72,907 liters	accident
FL St. Petersburg	1/13/78	Chlorine	109 kg	unload
FL Wildwood	2/18/78	Phosphoric Acid	92,396 kg	derailment
FL Youngstown	2/26/78	Chlorine	40,823 kg	derailment
GA Dublin	7/08/77	Calcium Hypochlorite	19,169 kg	accident
GA Augusta	1/16/77	Muriatic Acid	9,463 liters	accident
IL Centerville	5/29/76	Chlorosulfonic Acid	24,302 liters	derailment
IL Chicago Heights	5/31/77	Hydrochloric Acid	10,221 liters	derailment
IL Crescent City	10/10/77	Muriatic Acid	11,356 liters	accident
IL Davis Junction	3/31/77	Phosphoric Acid (MTL 69% Fert)	32,176 liters	derailment
IL Stoy	5/29/76	Sulphuric Acid	49,487 liters	derailment
IN Belleville	2/17/78	Phosphorus Pentasulfide	907 kg	accident
IN Ligoneer	5/08/71	Lead Arsenate	86 kg	accident

(continued)

TABLE 1 (continued)

State/City	Date	Chemical	Amount Spilled	How Spilled
KA Wichita	6/07/77	Toluene	507 liters	leak
KY Benson	12/07/77	Acrylonitrile	26,498 liters	derailment
KY Leon	1/30/78	Acrylonitrile	389,897 liters	derailment
KY Louisville	10/18/77	Trimethylamine	189 liters	rail leak
KY Louisville	9/27/76	Nitric Acid	7,076 kg	accident
KY Russell	2/01/78	Butyl Acetate	38,971 liters	rail leak
LA Avondale	2/02/78	Formaldehyde	757 liters	derailment
MD Slabtown	6/27/72	Phenol	94,635 liters	derailment
MA Deerfield	12/03/77	Sodium Hydroxide	5,678 liters	leak
MN St. Paul	7/25/74	Chlordane	37 liters	leak
MO Clarksville	8/19/77	Acetic Acid	9,822 kg	leak
MO Hannibal	4/20/78	Monochlorobenzene	189 liters	derailment
MO Lamar	12/16/76	Ethylene Dichloride	3,785 liters	accident
MO Needles	1/19/77	Toluene	49,210 liters	derailment
MS Brohman	2/04/78	Phenol	83,279 liters	derailment
MS Duffee	7/04/77	Caustic Soda	60,566 liters	derailment
MS Duffee	7/05/77	Caustic Soda	5,678 liters	derailment
MS Sebastopol	2/09/77	Sulphuric Acid	41,730 kg	derailment
MS Yazoo City	6/22/77	Insecticide	Various	accident
MT Whitefish	12/15/77	Sodium Hydroxide	1,950 kg	rail leak
NC Addor	12/13/76	Acetic Acid	78,297 liters	derailment
NC Charlotte	11/23/76	Styrene Monomer	189 liters	leak
NC Charlotte	1/28/77	Acetic Acid	18,688 kg	accident

(continued)

TABLE 1 (continued)

State/City	Date	Chemical	Amount Spilled	How Spilled
NC Clarkton	8/04/77	Chromic Acid Solid	90 kg	derailment
NC Hamlet	1/06/76	Toluene	5,678 kg	accident
NC Silver City	8/23/78	Toluene	7,571 liters	accident
NC S. Rocky Mtns.	6/24/78	Phosphoric Acid	725,748 kg	derailment
NE Hastings	8/02/76	Phosphoric Acid	90,968 kg	derailment
NJ Jersey City	2/07/77	Chlorobenzene	208 liters	leak
NJ Matawan	5/19/77	Toluene	2,900 liters	leak
NJ Metuchen	6/22/77	Caustic Potash	78,278 kg	derailment
NM Tucumcari	3/26/76	Parathion	45 kg	leak
NY Brooklyn	2/07/73	Zinc Cyanide	91 liters	leak
NY E. Shohola	11/07/76	Acetaldehyde	112,502 liters	derailment
NY Poughkeepsie	2/06/76	Muriatic Acid	26,498 liters	derailment
NY Rensselear	6/06/72	Formaldehyde	18,927 liters	accident
NY Syosset	3/29/77	Nitric Acid	1,136 liters	leak
OH Apco	12/23/77	Acetic Acid	37,854 liters	derailment
OH Ashtabula	11/04/77	Caustic Potash	37,854 liters	puncture
OH Bellevue	2/08/78	Caustic Potash	5,216 liters	rail leak
OH Cincinnati	4/17/77	Hydrochloric Acid	17,034 liters	derailment
OH Dayton	6/11/74	Acrylonitrile	31,642 liters	derailment
OH Hanover	1/22/77	Ethyl Acrylate, Ethylene Oxide, Acetaldehyde	227,125 liters total	derailment
OH Kingsville	8/25/78	Phosphorus Trichloride	14,519 kg	accident
OH Koppers	1/26/78	Phenol	5,648 liters	unload
OH Northfield	10/20/76	Malathion	189 liters	leak
OK Goultry	8/05/77	Ammonia	2,721 kg	leak
OK Kingfisher	4/16/77	Hydrochloric Acid	34 liters	accident

(continued)

TABLE 1 (continued)

State/City	Date	Chemical	Amount Spilled		How Spilled
OR Hinkle	4/07/78	Phosphoric Acid	91,580	kg	rail accident
PA Jim Thorpe	10/29/77	Caustic Soda	3,785	liters	derailment
PA Marshall Creek	1/07/77	Cyanide Compound	20	liters	accident
PA Pond Eddy	1/14/78	Acetaldehyde	103,720	liters	derailment
PA Spring City	3/01/77	Chlorobenzene	208	liters	leak
PA Trainer	2/16/76	Carbon Bisulfide	5,004	liters	derailment
SC Estill	8/04/77	Nitric Acid	3,592	kg	accident
TN Bean Sta.	8/21/78	Propionic Acid	15,899	liters	accident
TN Kingston	3/05/73	PCB	5,678	liters	accident
TX Andrews	12/15/76	Hydrochloric Acid	17,034	liters	accident
TX Canyon	11/22/78	Cyclohexane	3,028	liters	derailment
TX Hourd	9/27/77	Hydrochloric Acid	2,839	liters	accident
TX Houston	5/28/77	Sulfuric Acid	1,136	liters	accident
TX Houston	11/22/77	Sulfuric Acid	708	kg	accident
TX Justin	3/09/78	Butyl Acetate	76,545	liters	derailment
TX Luffins	10/20/77	Hydrochloric Acid	7,571	liters	accident
TX Port Allen	8/05/77	Sulfuric Acid	15,086	kg	accident
TX Weimar	3/12/78	Analine	2,271	liters	rail leak
TX Westhoff	7/01/76	Monoethanolamine	17,391	kg	accident
UT Holden	8/17/77	Benzol	5,867	liters	accident
UT Wallsburg	6/17/77	Toluene	14,146	liters	accident
VA Roanoke	7/29/75	Toluene	14,309	liters	accident
WA Humorist	10/08/77	Phosphoric Acid	113,562	liters	derailment
WA Pullman	9/05/77	Ammonia	11,356	liters	leak

(continued)

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 287)
TYPING GUIDE SHEET

TABLE 1 (continued)

State/City	Date	Chemical	Amount Spilled	How Spilled
WI Cameron	11/15/78	Xylene	10,410. liters	accident
WI Elkhorn	7/30/77	Arsenic Trioxide	8,582 kg	derailment
WI Milwaukee	2/24/78	Ethyl Benzene	38,675 liters	rail rupture
WV Gauley Bridge	5/19/76	Methyl Methacrylate	18,262 kg	accident
WV Kroy	4/21/78	Nitrobenzen	189 liters	derailment
WV Orleans Rd	11/28/77	Ammonia	121,133 liters	derailment
WV Sandstone	1/15/76	Acrylonitrile	151,416 liters	derailment

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 287)
TYPING GUIDE SHEET

techniques used to treat the damaged areas. These spills and the methods employed to restore the damaged lands are discussed in detail in the following sections.

PCB SPILL, KINGSTON, TENNESSEE

Background of Spill

On March 5, 1973, a truck accident and spill occurred on Highway 58 near Kingston, Tennessee. Details of the spill are presented in Table 2. The material spilled was composed of polychlorinated biphenyls (Aroclor 1254) and a proprietary solvent mixture of polychlorinated benzenes. The spill occurred on land which was used as pasture. The spill site was in a water shed approximately 1 km long which drained into a lake (Figure 1). In addition, it was found that the spill migrated across the road affecting a second watershed.

The rural area affected had several houses which received their drinking water from wells at, or near, the contaminated watershed. When heavy rains fell at the site, distributing the PCBs horizontally and vertically in the soil, a massive clean-up of the area was initiated.

Climate of Spill Area

Average weather conditions for the spill site from 1942-1970 are presented in Table 3. East-Central Tennessee receives the greatest amount of rainfall from December to March. The high wind months overlap with the high precipitation months, occurring from February through April and averaging near 15 kmph (9 mph) from the northeast. The PCB spill occurred during the time of above average wind and precipitation levels. The precipitation data for the 1973-1975 is presented in Table 4. In March, 1973,when the spill occurred, 32 cm (12.44 inches) of rain fell in the area, 19 cm (7.61 inches) above the average. Heavy rainfall was also reported in the following three months: April to June. These three months had a combined rainfall 24.5 cm (9.65 inches) above the normal levels. The heavy precipitation in the spill area increased the hazards from the spilled Aroclor 1254.

Geology of Spill Area

Moein (1976) studied the geological features of the spill site. "The geological formations of the site area strike 40° northeasterly on the average, and normal dips are $25-35^\circ$ to the southeast. The rocks underlying the total spill area are part of the Knox dolomite group. A shaley limestone series known as the Chickamauga formation lies to the southeast and upon the Knox group. The Knox of the area is the usual sequence of thin to massive-bedded dolomite (high $MgCO_3$ as compared to limestone with its high $CaCO_3$) and is well fractured.

The overburden above the Knox group is thick--in the 15.2 to 45.6 m range. The primary overburden is made up of clays mixed heavily with chert fragments. On top of the clay is a zone of top soil ranging from 0 to 122 cm in thickness. The top soil allows for ease of percolation while the clays are penetrable primarily through the fracture crevices of the chert."

BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD; BEGIN SECTIONS HERE

TABLE 2. BACKGROUND OF PCB SPILL KINGSTON, TENNESSEE

Chemical Spilled	Askarel, Aroclor 1254 (PCB)
Class of Material	---------
Amount Spilled	5,678 liters
How Occurred	Truck accident
Date	March 5, 1973
Time	---------
Location	Kingston, Tennessee
On-site Spill Coordinator	Al J. Smith EPA Region IV Atlanta, Georgia

----- data not available

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA, OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
PAGE NUMBER

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 287)
© U.S. GOVERNMENT PRINTING OFFICE 1980-680-839
TYPING GUIDE SHEET

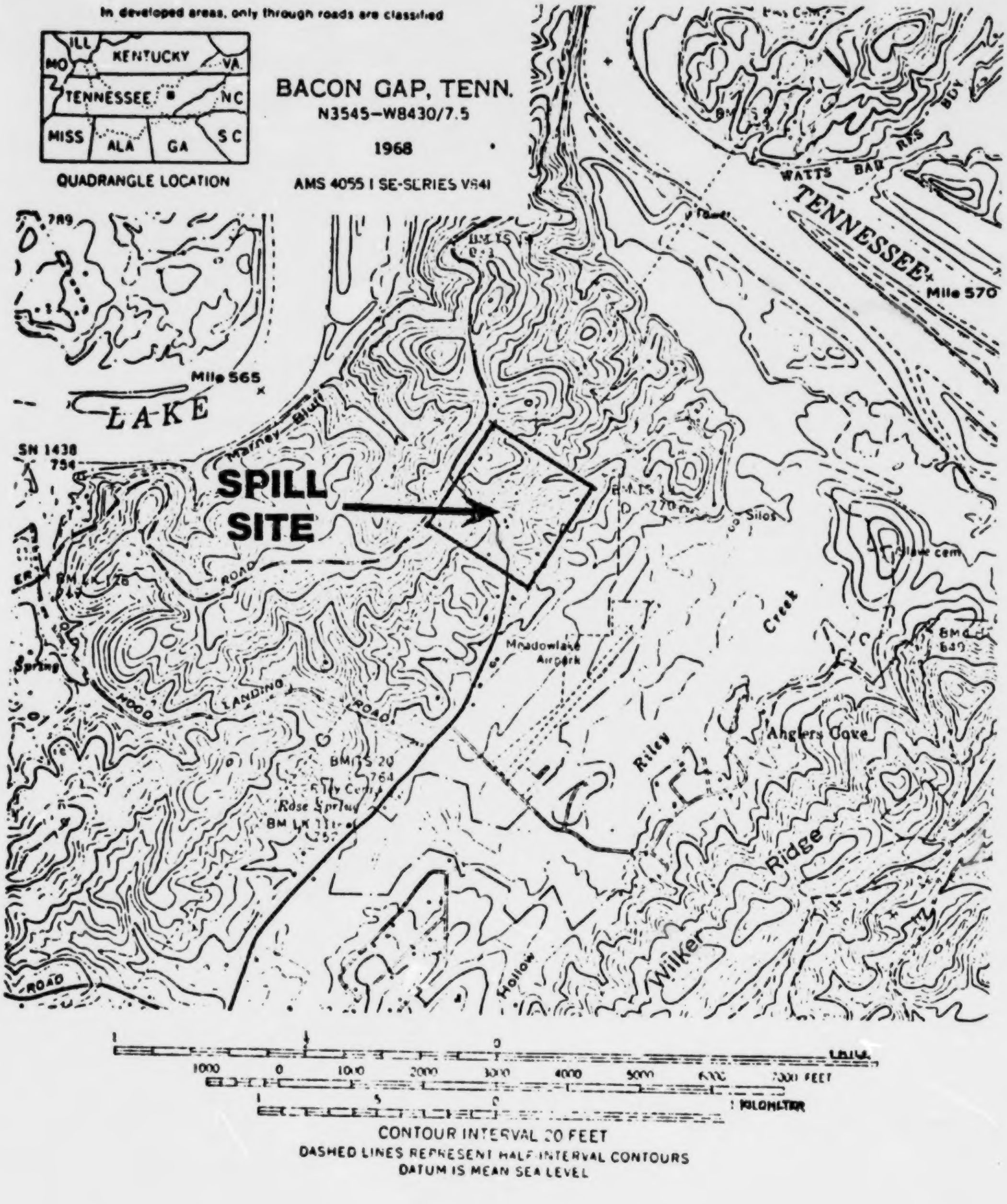

In developed areas, only through roads are classified
ILL
MO
KENTUCKY
VA
TENNESSEE
NC
MISS
ALA
GA
SC
QUADRANGLE LOCATION
BACON GAP, TENN.
N3545—W8430/7.5
1968
AMS 4055 I SE-SERIES V841
WATTS BAR
TENNESSEE
Mile 570
Mile 565
LAKE
Marney Bluff
SN 1438
754
SPILL SITE
Silos
ROAD
HOOD LANDING ROAD
Spring
Meadowlake Airpark
Creek
Riley
Anglers Cove
Rose Spring
BM TS 20
764
Wilker Ridge
Hollow
ROAD
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 KILOMETER
CONTOUR INTERVAL 20 FEET
DASHED LINES REPRESENT HALF INTERVAL CONTOURS
DATUM IS MEAN SEA LEVEL

Figure 1. Topography of spill site, Kingston, Tennessee (Moein, 1976).

TABLE 3. WEATHER CONDITIONS - KINGSTON, TENNESSEE AREA (RUFFNER AND BLAIR, 1978)

Month	Average Temperature °C (°F)	Average Precipitation cm	(inches)	Average Wind Speed kmph	(mph)	
January	4.7 (40.5)	11.6	(4.59)	13.1	(8.2)	NE
February	5.8 (42.5)	12.0	(4.73)	13.9	(8.7)	NE
March	9.6 (49.4)	12.2	(4.83)	14.7	(9.2)	NE
April	15.0 (59.0)	9.2	(3.64)	14.7	(9.2)	NE
May	19.6 (67.4)	9.0	(3.58)	11.6	(7.3)	SW
June	24.3 (75.8)	8.8	(3.47)	10.7	(6.7)	SW
July	25.7 (78.4)	12.0	(4.72)	10.0	(6.3)	S
August	25.0 (77.0)	8.7	(3.43)	9.1	(5.7)	NE
September	22.2 (72.1)	6.4	(2.53)	9.4	(5.9)	NE
October	15.7 (60.3)	6.6	(2.63)	9.2	(5.8)	NE
November	9.1 (48.4)	8.0	(3.15)	11.5	(7.2)	NE
December	5.0 (41.0)	10.8	(4.26)	12.0	(7.6)	NE
Yearly Average	12.3 (54.3)	115.5	(45.51)	11.6	(7.3)	NE

EPA Form 2350-4 (4-80)
(PREVIOUSLY EIN. EPA FORM 287)
TYPING GUIDE SHEET

TABLE 4. MONTHLY PRECIPITATION LEVELS FROM 1973-1975
AT PCB SPILL AREA (MOEIN, 1976)

	Total Precipitation in Centimeters (Inches)					
Month	1973*		1974*		1975*	
January	11.4	(4.51)	25.4	(10.00)	15.0	(5.93)
February	8.3	(3.30)	13.7	(5.41)	14.9	(5.90)
March	31.5	(12.44)	9.5	(6.97)	33.5	(13.19)
April	11.5	(4.55)	8.9	(3.54)	6.2	(2.45)
May	25.0	(9.82)	18.6	(7.36)	16.3	(6.43)
June	18.6	(7.33)	6.9	(2.72)	11.3	(4.47)
July	14.7	(5.81)	4.1	(1.64)	9.2	(3.63)
August	9.0	(3.58)	13.7	(5.43)	5.0	(2.00)
September	11.0	(4.32)	7.8	(3.10)	13.1	(5.17)
October	8.0	(3.12)	4.0	(1.59)	13.2	(5.23)
November	24.7	(9.74)	10.8	(4.26)	9.8	(3.87)
December	21.2	(8.38)	17.8	(7.04)	11.8	(4.65)

*U.S. Department of Commerce, 1973; 1974; 1975.

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 337)
TYPING GUIDE SHEET

Soil temperatures measured to a depth of 142 cm (56 inches) are presented in Figure 2. The data indicate a general decrease in temperature with depth, the largest drop occurring over the first 20-30 cm (8-12 inches). The drainage of the spill area was in a northeastern direction into a lake .8 km away. Mud of the spilled material migrated toward the lake.

Response to the Spill

The heavy rainfall during the month of the spill and the geology of the area increased the chances for possible contamination of two watersheds and several wells in the spill area. Because of these factors, a large scale removal of the contaminated soil was initiated on March 14, 1973, nine days after the spill. A total of 11,531 metal drums of packed soil were removed from the spill site. The excavated areas were then sealed, backfilled and packed with uncontaminated soil.

Extensive sampling of the water and soil in the spill areas was conducted by the EPA and Stewart Laboratories, Inc. A follow-up study on the persistence of the PCBs in the contaminated soil was conducted over the summer of 1975. Another sampling program is planned for the summer of 1979.

Environmental Levels of Spilled Material

PCB levels in the soil are presented in Table 5. PCBs were found at depths of over 1.5 meters in 1973. Comparing the PCB levels in the soil samples collected in 1973 and 1975 revealed that the distribution in the clay soil was non-uniform. This was due in part of "hot spots" along root systems and through fractured chert found in the clay matrix (Moein et al., 1976).

Further analysis of the PCBs found in the soil in 1975 indicated the same distribution of chlorines per biphenyl as found in 1973. No PCB degradation products were found in the 1975 soil samples. These two pieces of information further supported the lack of degradation of PCBs in the soil (Moein et al., 1976).

PCB levels in water samples collected in 1973 were usually below the 0.5 ppb detection limit. However, two samples, a spring below the spill area and a well 30 m from the excavation area, had levels greater than 0.5 ppb. The highest level was 2.1 ppb. In 1975, eight wells, a spring and a creek were sampled. All samples were below the 0.5 ppb limit for PCBs (Moein et al., 1976).

The behavior of the polychlorinated benzene solvent was different from the PCBs. Soil samples collected in 1973 indicated that tetra- and pentachlorobenzenes were retained in soil. However, the other parts of the solvent, mainly trichlorobenzenes, rapidly leached into the ground water. This trend is illustrated in Figure 3 which shows the solvent levels in a well near the spill site. Shortly after the spill the solvent levels were near 500 ppb. These levels were reduced to 1 ppb by August, 1975.

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD, BEGIN SECTIONS HERE

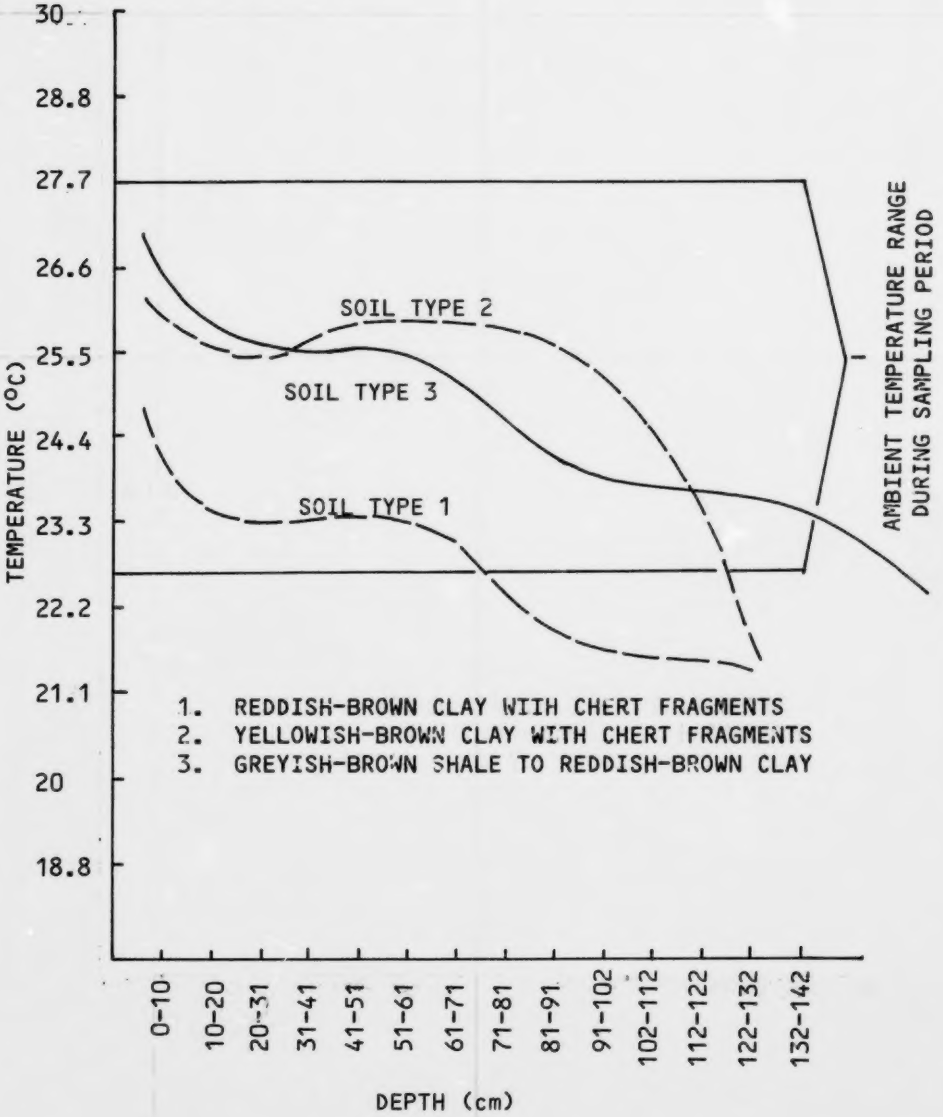


Figure 2. Temperature of three soil types with depth, Kingston, Tennessee (Moein, 1976).

BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
BEGIN LAST LINE OF TEXT
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TABLE 5. COMPARISON OF ANALYTICAL DATA FROM CORE SAMPLES COLLECTED IN 1973 AND 1975 (MOEIN _et_ _al_., 1976)

Core Site Identification	Collection Depth Ranges (centimeters) Year 1973	Collection Depth Ranges (centimeters) Year 1975	Analytical Results--1973 PCB Concentration (mg/kg)	Analytical Results--1973 No. of Samples	Analytical Results--1975 PCB Concentration (mg/kg)	Analytical Results--1975 No. of Samples
Part I. 10 cm Test Cores						
RL	22.8- 88.9	48.2- 88.9	1.25-5.87	3	<0.05-14.5	17
UC	22.8-152.4	53.3- 93.9	0.06-0.27	4	<0.05-2.24	16
JF	22.8- 47.5	48.2-129.5	2.04-7.67	3	<0.05-0.36	32
Part II. 10 cm Core Samples						
EK	22.8- 88.9	38.1- 78.7	0.86-2.76	4	<0.05-0.27	4
SR	22.8- 47.5	22.8-104.1	0.27-0.43	3	<0.05-0.89	8
CC	22.8- 91.4	22.8- 63.5	0.88-2.20	3	<0.05-0.40	4
SM	22.8- 91.4	50.8- 91.4	0.44-0.85	3	<0.05-1.10	4
FM	22.8-167.6	88.9-165.1	1.64-3.44	3	<0.05-1.27	8
Part III. 40 cm Core Samples						
LJ	22.8-109.2	22.8-104.1	0.55-1.45	3	<0.05-7.36	2
MB	22.8- 93.9	22.8- 63.5	1.60-5.86	3	3.69	1
KH	22.8- 93.9	53.3- 93.9	4.10-6.56	3	<0.05	1
SW	22.8- 32.5	30.4- 71.1	0.19-1.42	3	23.8	1
JR	22.8 -50.8	22.8- 63.5	0.52-2.40	2	5.00	1
GW	22.8-101.6	22.8- 63.5	0.09-0.29	3	3.23	1
TE	22.8-157.4	22.8- 63.5	0.07-0.21	4	<0.05	1
JD	22.8- 88.9	22.8- 63.5	0.27-0.82	3	0.17	1
MM	22.8-167.6	22.8-185.4	0.23-6.72	4	<0.05-0.27	4
GE	22.8- 88.9	48.2- 88.9	0.68-2.32	3	0.32	1
CT	7.6- 15.2	7.6- 48.2	0.12	1	0.16	1
MT	22.8-101.6	22.8-104.1	1.37-3.00	3	0.89-4.35	2
BT	22.8- 91.4	22.8-104.1	3.44-3.11	3	1.34-10.1	2

(continued)

TABLE 5 (continued)

Core Site Identification	Collection Depth Ranges (centimeters) Year 1973	Collection Depth Ranges (centimeters) Year 1975	Analytical Results--1973 PCB Concentration (mg/kg)	Analytical Results--1973 No. of Samples	Analytical Results--1975 PCB Concentration (mg/kg)	Analytical Results--1975 No. of Samples
LP	7.6- 15.2	7.6- 48.2	3.26	1	3.41	1
JS	7.6- 15.2	10.1- 50.8	3.85	1	5.62	1
FA	22.8-106.6	22.8-104.1	1.85-8.50	3	<0.05	2
PT	7.6- 15.2	7.6- 48.2	0.50	1	66.6	1
FO	22.8- 91.4	22.8-104.1	0.05-0.21	3	<0.05	2
AA	15.2- 22.8	7.6- 48.2	0.60	1	0.34	1
EL	22.8-127.0	22.8-104.1	0.11-1.00	3	0.05	2
PS	0.0- 45.7	5.0- 22.8	0.09-0.69	3	2.04	1
DV	22.8- 86.3	22.8- 63.5	0.21-0.58	3	<0.05	1
SS	22.8- 91.4	22.8-104.1	0.46-5.70	3	<0.05	2
HH	22.8-167.6	22.8-104.1	0.05-1.35	3	0.12-0.67	2
AM	22.8- 96.5	22.8- 63.5	0.09-0.15	3	<0.05	1
VT	7.6- 15.2	0.0- 40.6	0.72	1	0.17	1
JE	47.5- 73.6	47.5- 99.0	0.16-0.20	2	<0.05	1
BA	86.3- 94.0	53.3- 93.9	0.12	1	<0.05	1
TR	83.8-104.1	63.5- 93.9	< 0.05	2	<0.05	1
CV	83.8-132.0	83.8- 47.5	<0.05-1.39	4	<0.05	1
PQ	22.8- 55.8	22.8- 63.5	0.40-0.44	2	0.21	1
MD	0.0- 45.7	7.6- 48.2	0.76-7.50	3	0.15	1
BS	22.8-122.0	25.4-147.3	0.27-15.8	4	0.13-7.45	3
HT	22.8-139.7	22.8-104.1	0.13-4.80	4	<0.05-0.16	2
ZZ	22.8-101.6	22.8-104.1	0.47-7.50	3	0.29-0.50	2
BR	0.0- 45.7	7.6- 48.2	0.63-6.00	3	0.91	1
SL	22.8-155.0	22.8-63.5	0.05-0.20	3	2.05	1

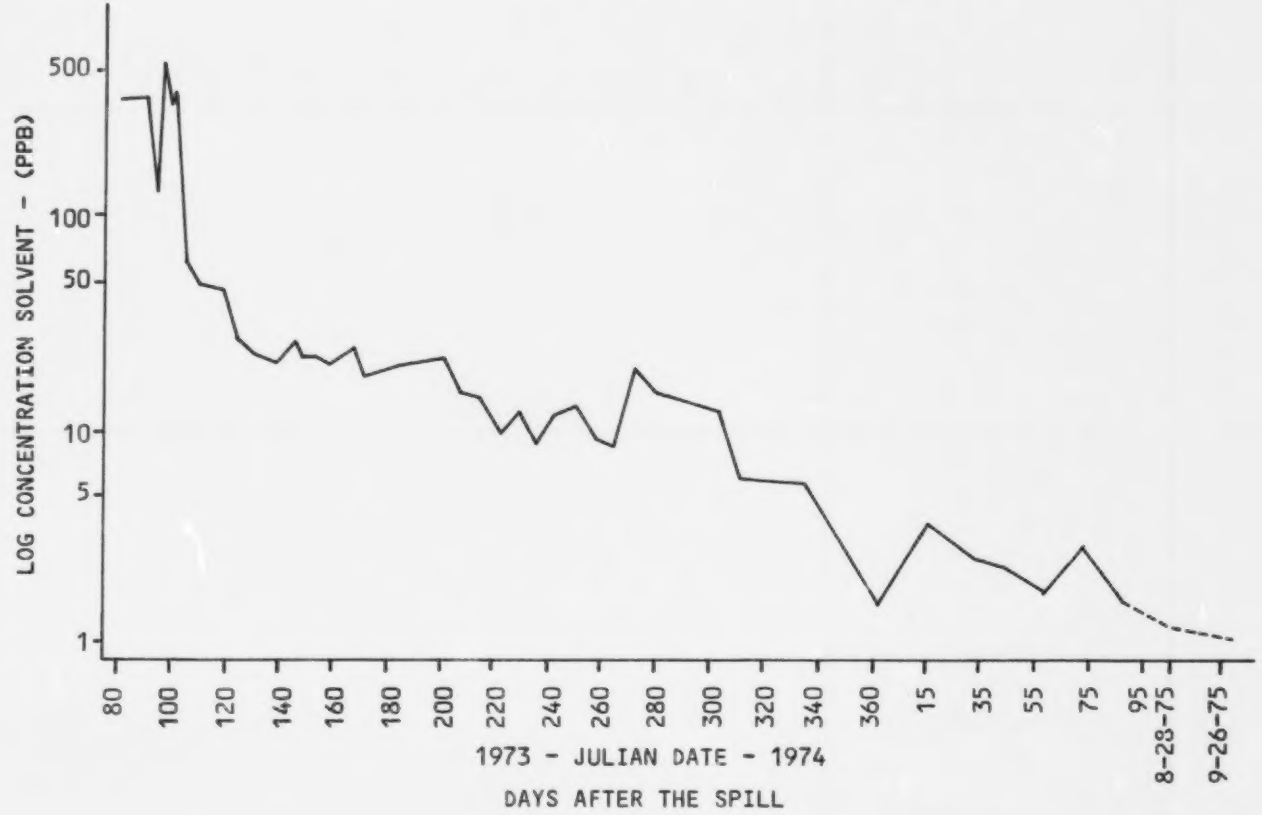


Figure 3. Solvent concentration profile - well located closest to PCB spill site (Moein, 1976).

Biological Damage to Area

The spill area was sparsely wooded with pines and hardwoods. Some damage to trees and shrubs was observed in the area of highest contamintion. No mammals, reptiles or amphibians were observed in the area. By 1975, there was heavy vegetative growth at the spill site and insects and garter snakes were noted in the area. Also, earthworms were found in the core samples collected at the site.

In 1975, microbial data were collected from the soil samples and compared to pH, soil moisture, soil type and PCB levels. The data comparing microbial counts to pH are presented in Table 6. Bacteria and actinomycete numbers were highest at pH levels between 4.0-4.5. The effects of moisture content of the soil on microbial numbers are presented in Table 7. Bacteria and actinomycete levels were greatest at a soil moisture content between 5-10%. The fungi count was highest at soil moisture levels from 0-5%.

Microbial numbers compared to soil type are presented in Table 8. Only three of the 11 soil types identified were sampled relatively frequently. Of these soil types, the yellowish-brown clay had the highest microbial content.

The reddish-brown clay with chert fragments had the lowest numbers of actinomycetes and fungi. The data comparing PCB levels in the soil with microbial levels are presented in Table 9. These data indicate no trend concerning the toxicity of PCBs to microorganisms. Although higher microbial levels were observed in soil containing PCB levels ranging from .05-5 ppm, other physical and chemical factors of the soils would have to be considered before assessing the effects of PCBs on soil or microorganisms.

ACRYLONITRILE SPILL, LEON, KENTUCKY

Background of the Spill

Details of the acrylonitrile spill on January 30, 1978, are presented in Table 10. Specifically, 4 tank cars of acrylonitrile were involved in a 14-car derailment. The derailment occurred at the Highway 7 overpass of the C & O Railroad near Leon, Kentucky. A fire was involved, but was primarily around the tank cars. A map of the surrounding area is presented in Figure 4. The map shows that the spill occurred in a rural area near the town of Grayson. A close-up of the spill area is presented in Figure 5. The acrylonitrile cars were positioned very close to drainage ditches leading to a river.

The derailment occurred about 91 m from the Little Sandy River which is a water source for Grayson (10 km downstream) and Greenup (67 km downstream). A drainage ditch and a concrete culvert were dammed to prevent any drainage from the spill site into the river.

Most of the derailed cars were involved in a fire, the major part of which occurred near the tracks. Of the 390,000 liters of acrylonitrile involved in the spill, 116,000 liters were recovered and 284,000 liters were lost or burned.

TABLE 6. MICROBIAL POPULATIONS RELATIVE TO pH OF SOIL SAMPLES (MOEIN, 1976)

pH Ranges	Criterion(1) for Average	Average Microbiological Counts (Per Gram of Soil)			Numbers of Samples
		Bacteria	Actinomycete	Fungi	
4.0-4.5	High	90324	1043	4444	49
	Low	88447	861	4275	
4.6-5.0	High	215644	1299	2901	66
	Low	215250	1255	2845	
5.0 Up	High	264315	9970	2426	27
	Low	264315	9959	2426	

(1)For microbial counts per gram of soil when the number of organisms is a "less than" number, the high averages are calculated with "less than" values taken to be positive. The low averages are calculated with the "less than" values taken to be zero. The actual mean of the samples must lie between the high average and the low average.

TABLE 7. MICROBIAL POPULATIONS RELATIVE TO MOISTURE CONTENT OF SOILS (MOEIN, 1976)

Moisture (% by Weight)	Criterion[1] for Average	Average Microbiological Counts (Per Gram of Soil) Bacteria	Actinomycete	Fungi	Number of Samples
0-5	High	289500	7756	8633	9
	Low	289500	7756	8633	
5-10	High	385630	11476	4813	23
	Low	385630	11476	4813	
10-15	High	236156	1503	2202	32
	Low	236156	1503	2202	
15-20	High	135940	407	1976	42
	Low	135940	407	1976	
20-25	High	27240	200	3791	35
	Low	27240	200	3791	
25-30	High	100000	100	200	1
	Low	100000	100	200	

[1] For microbial counts per gram when the number of organisms is a "less than" number, the high averages are calculated with "less than" values taken to be positive. The low averages are calculated with the "less than" values taken to be zero. The actual mean of the samples must lie between the high average and the low average.

TABLE 8. MICROBIAL POPULATIONS RELATIVE TO SOIL TYPES (MOEIN, 1976)

Soil Characteristics	Criterion(1) for Average	Average Microbiological Counts (Per Gram of Soil) Bacteria	Actinomycete	Fungi	Samples/Soil Type
Reddish-brown clay with chert fragments	High	136628	469	2707	81
	Low	136530	427	2696	
Yellowish-brown clay with chert fragments	High	364796	12557	6093	27
	Low	360722	12183	3685	
Greyish-brown shale to reddish-brown clay	High	84333	2150	1543	3
	Low	84333	2150	1543	
Reddish-brown clay	High	138667	158	3984	6
	Low	138667	125	3984	
Greyish-brown silty clay with chert fragments	High	207182	723	3127	11
	Low	207182	723	3127	
Greyish-brown to reddish-brown silty clay with numerous chert fragments	High	52375	150	1813	4
	Low	52375	100	1813	
Greyish-brown to reddish-brown clay with chert fragments	High	31500	133	1683	3
	Low	31500	133	1683	
Reddish-brown silty clay with chert fragments	High	110750	100	4525	2
	Low	110750	0	4525	
Yellowish-brown silty clay with chert fragments	High	78000	500	1900	1
	Low	78000	500	1900	
Greyish-brown clay with chert fragments	High	190333	317	1100	8
	Low	190333	317	1067	
Loam (Control)	High	340000	11000	1500	1
	Low	340000	11000	1500	

(1) The high averages are calculated with "less than" values taken to be positive (<.1 taken as .1). The low averages are calculated with the "less than" values taken to be zero. The actual mean of the samples must lie between the high average and the low average.

EPA Form 2350-4 (6-80)
(PREVIOUSLY CIN: EPA FORM 327)
TYPING GUIDE SHEET

TABLE 9. MICROBIAL POPULATIONS RELATIVE TO PCB CONCENTRATION IN CORE SAMPLES (MOEIN, 1976)

PCB Concentration (mg/kg soil)	Criterion[1] for Average	Average Microbiological Counts (Per Gram of Soil) Bacteria	Actinomycete	Fungi	Number of Samples
<.05	High	82825	1066	3378	80
	Low	81475	936	3242	
.05-5.0	High	273535	5708	3269	55
	Low	273353	5643	3249	
5.0-10.0	High	920750	1500	4638	4
	Low	920750	1475	4638	
10.0-30.0	High	140750	375	2700	2
	Low	140750	375	2700	
30.0-66.6	High	160000	100	750	1
	Low	160000	100	750	

(1) For microbial counts per gram when the number of organisms is a "less than" number, the high averages are calculated with "less than" values taken to be positive. The low averages are calculated with the "less than" values taken to be zero. The actual mean of the samples must lie between the high average and the low average.

TABLE 10. BACKGROUND OF ACRYLONITRILE SPILL NEAR LEON, KENTUCKY

Chemical Spilled	Acrylonitrile
Class of Material	Flammable liquid
Amount Spilled	389,897 liters (105,991 liters recovered)
How Occurred	Derailment
Date	January 30, 1978
Time	5:53 a.m.
Location	Leon, Kentucky
On-Site Spill Coordinator	Allen Bartlett, EPA Region IV Atlanta, Georgia

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN-EPA FORM 287)
TYPING GUIDE SHEET

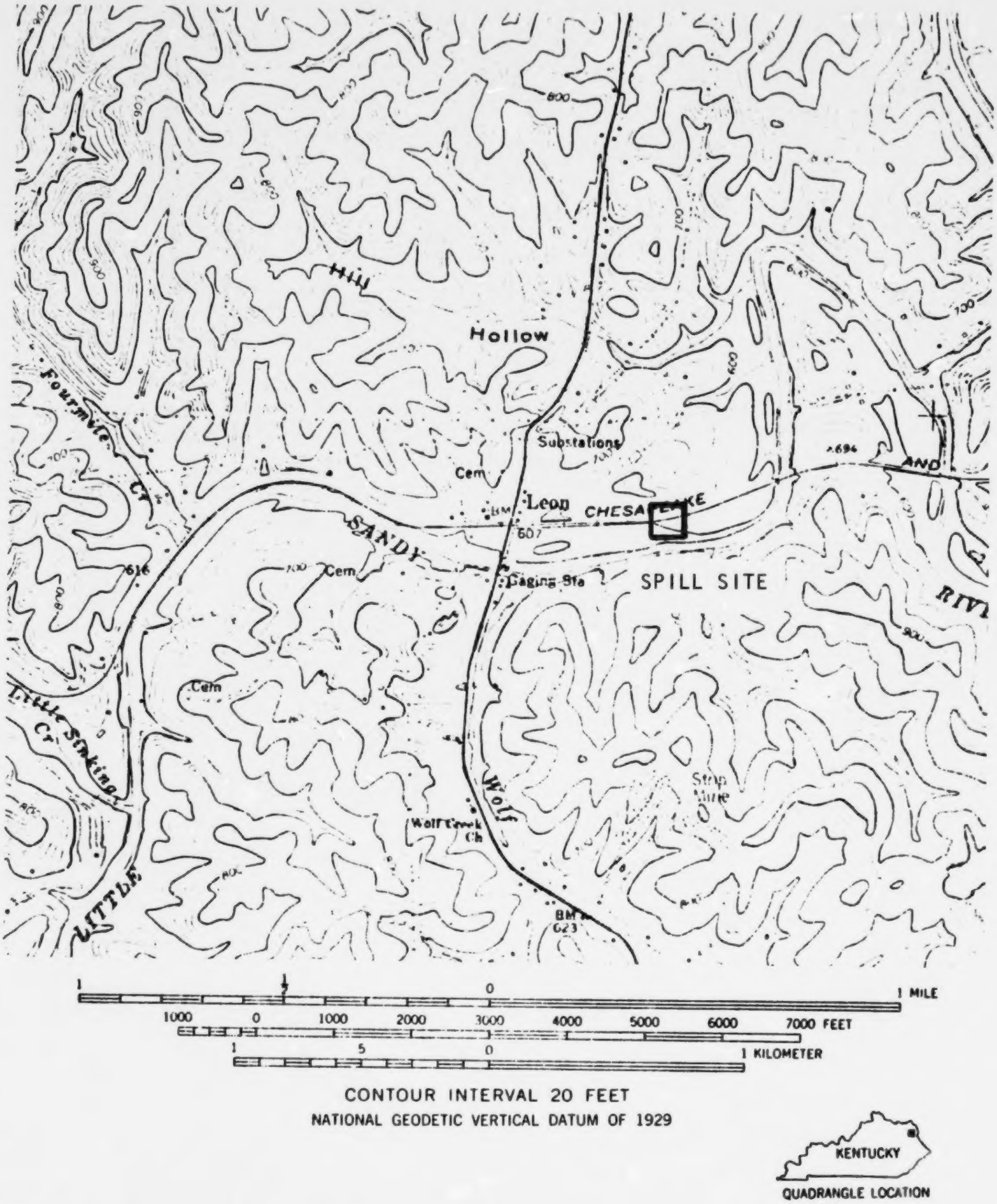

Hill
Hollow
Substations
Cem
Leon
BM
607
CHESAPEAKE
SANDY
Gaging Sta
SPILL SITE
RIVER
AND
694
Fourmile Cr
616
Cem
Cem
Little Sinking Cr
LITTLE
Wolf
Wolf Creek Ch
Strip Mine
BM 623
800
900
700
1
½
0
1 MILE
1000
0
1000
2000
3000
4000
5000
6000
7000 FEET
1
.5
0
1 KILOMETER
CONTOUR INTERVAL 20 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929
KENTUCKY
QUADRANGLE LOCATION

Figure 4. Acrylonitrile spill near Leon, Kentucky Topography of area (U.S. Geological Survey, 1978)

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
DROPPED HEAD; BEGIN SECTION HERE
CENTER OF PAGE
TOP OF IMAGE AREA
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

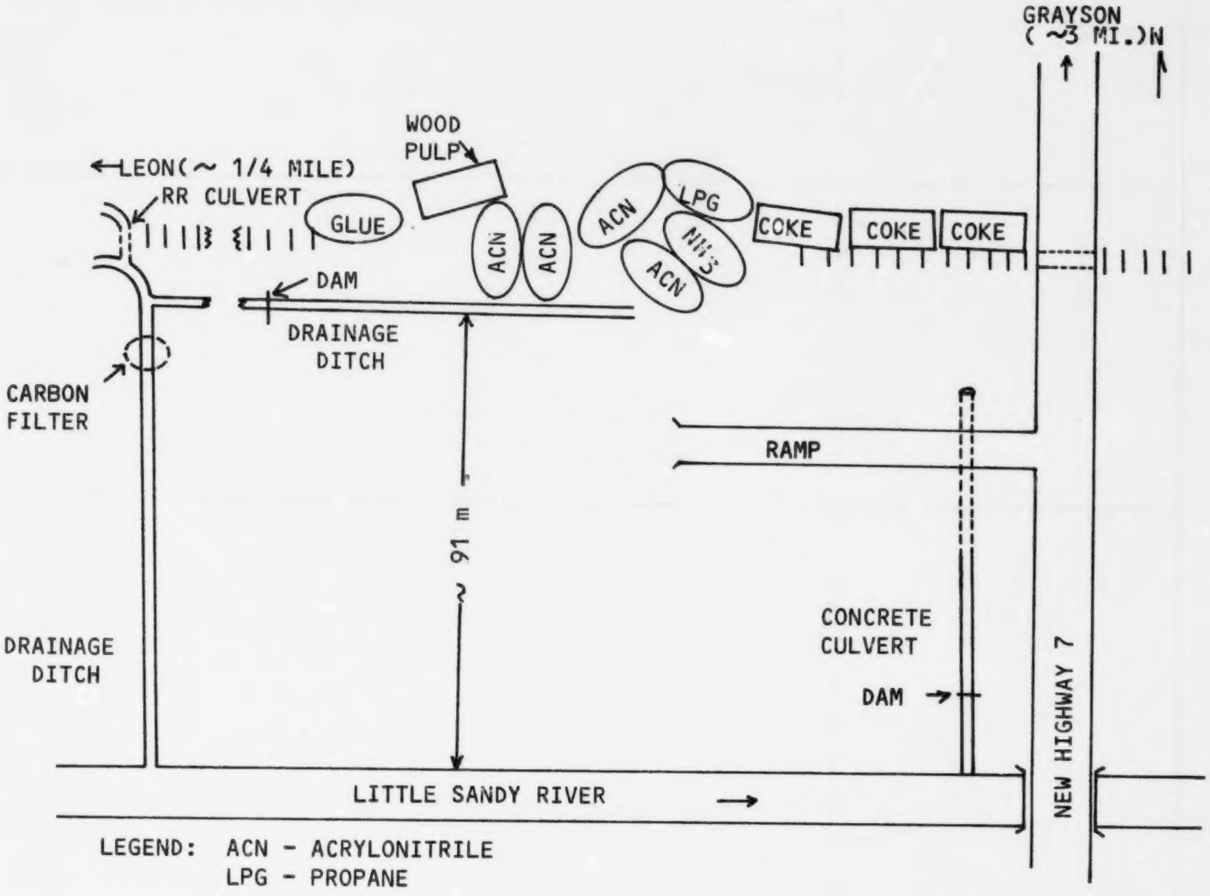

GRAYSON
(~3 MI.)
N
WOOD
PULP
←LEON(~ 1/4 MILE)
RR CULVERT
GLUE
ACN
ACN
ACN
LPG
NH3
ACN
COKE
COKE
COKE
DAM
DRAINAGE
DITCH
CARBON
FILTER
RAMP
~ 91 m
CONCRETE
CULVERT
DAM
DRAINAGE
DITCH
NEW HIGHWAY 7
LITTLE SANDY RIVER
LEGEND: ACN - ACRYLONITRILE
LPG - PROPANE

Figure 5. Spill site shortly after derailment (Bartlett, 1978).

Climate of Spill Area

The average weather conditions for the Leon, Kentucky area are presented in Table 11. The spill occurred in late January when frozen soil and snow were present. January through March have fairly high amounts of precipitation. Also, winds during the same period are usually greater than 19.4 kmph (11 mph) and are from a southerly direction.

Geology of Spill Area

The area has soils of a Muskingreen-Montivalla-Ramsey association.

Response to Spill

The area was evacuated for a two mile radius around the spill, due to the possibility of toxic fumes. On January 31, the on-site spill coordinator directed the damming of a drainage ditch and a culvert leading to the Little Sandy River. It appears that a large amount of the acrylonitrile was in the soil of the surrounding area. The water supply of Grayson and Greenup were both shut off the day of the spill.

Because of the danger of contamination of the Little Sandy River, Stewart Laboratory, Inc., sampled the soil and water from February 4-8 to determine the acrylonitrile levels. The sampling indicated that the chemical was leaking into the Little Sandy River and further methods would be needed to treat the spill site. The C & O Railroad contracted O & H Materials to construct 16 aeration pools to degrade the acrylonitrile. A closed system was constructed. Water from the contaminated area was treated in the aeration pools and reinjected into the soil. When the acrylonitrile concentrations in the water were less than 3 ppb, the effluent was released into the Little Sandy River (Liebenow, personal communication, 1979).

Environmental Levels of the Spilled Material

The locations of the core samples collected by Stewart Laboratories, Inc., are shown in Figures 6a and 6b. The positions of the train cars after the tracks were cleared are also shown in these Figures. Surface soil levels of acrylonitrile are presented in Table 12. From the soil samples, it appears that most of the acrylonitrile was located near the tracks or to the south of the tracks toward Little Sandy River.

More detailed information on soil cores is presented in Table 13. The cores indicate that acrylonitrile had penetrated the soil to a depth of at least 102 cm. Typical acrylonitrile levels in the Little Sandy River after the spill ranged from 0.4-0.6 ppm (Stewart Laboratories, Inc., in Bartlett, 1978).

Biological Damage in the Spill Area

Since the spill occurred in winter, biological damage was difficult to estimate. Some damage could have been produced by the fire after the derailment.

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 287)
TYPING GUIDE SHEET

TABLE 11. WEATHER CONDITIONS, LEON, KENTUCKY
(RUFFNER AND BLAIR, 1978)

Month	Average Temperature °C (°F)	Average Precipitation cm (inches)	Average Wind Speed kmph (mph)
January	0.2 (32.5)	11.4 (4.50)	17.6 (11.0)S
February	1.4 (34.5)	8.8 (3.50)	17.9 (11.2)SSW
March	5.7 (42.4)	11.3 (4.46)	19.0 (11.9)SSW
April	11.6 (52.9)	9.5 (3.76)	18.4 (11.5)SSW
May	17.0 (62.6)	9.0 (3.56)	14.7 (9.2)S
June	22.3 (72.2)	10.6 (4.21)	13.2 (8.3)S
July	24.2 (75.7)	10.7 (4.25)	11.8 (7.4)SSW
August	23.5 (74.4)	8.5 (3.37)	11.2 (7.0)S
September	20.5 (68.9)	7.1 (2.83)	12.8 (8.0)S
October	14.0 (57.3)	6.1 (2.44)	13.7 (8.6)S
November	6.5 (43.8)	8.0 (3.15)	16.9 (10.6)S
December	1.6 (34.9)	9.3 (3.68)	17.9 (11.2)S
Yearly Average	12.4 (54.4)	111.0 (43.71)	15.5 (9.7)

EPA Form 2360-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 287)

TYPING GUIDE SHEET

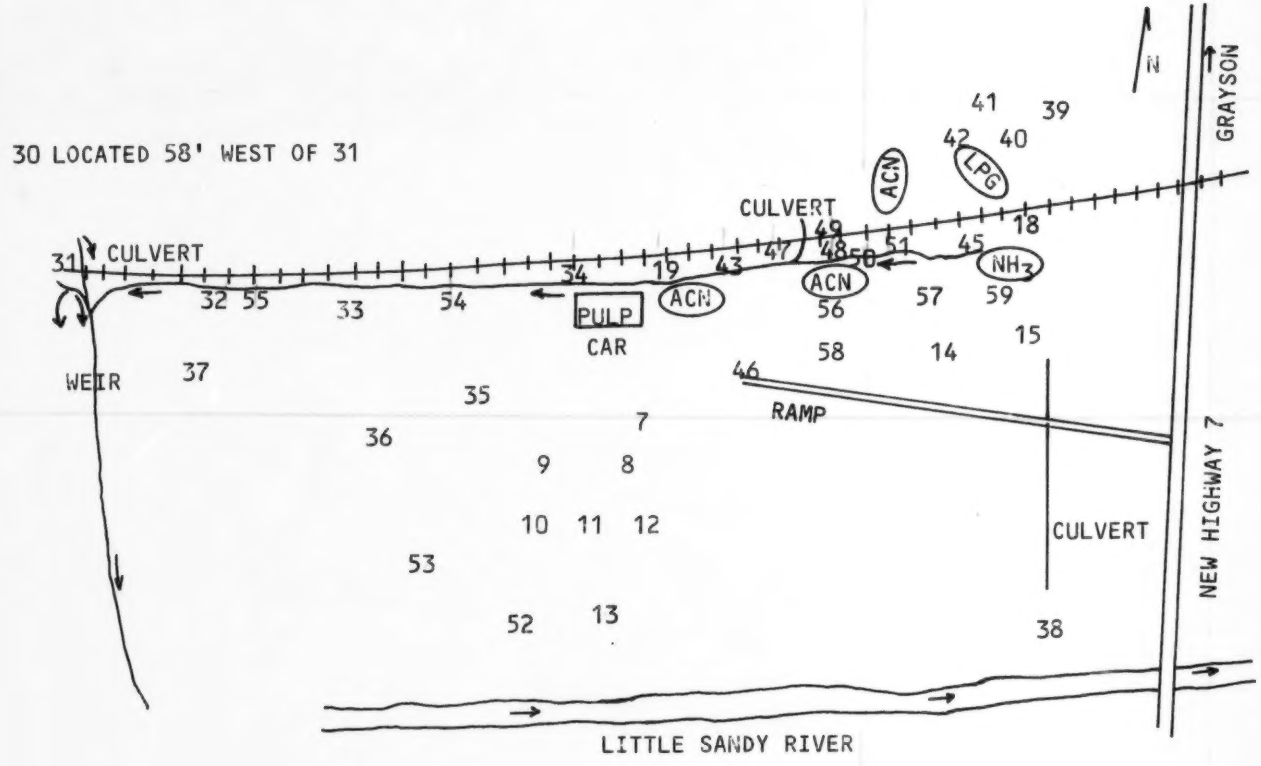

30 LOCATED 58' WEST OF 31
N
GRAYSON
NEW HIGHWAY 7
CULVERT
CULVERT
CULVERT
WEIR
PULP
CAR
RAMP
ACN
ACN
ACN
LPG
NH3
LITTLE SANDY RIVER
31
32
55
33
54
34
19
43
47
49
48
50
51
45
18
42
41
40
39
56
57
59
58
14
15
46
37
35
36
7
8
9
10
11
12
53
52
13
38

Figure 6a. Numbered soil sampling locations in spill area west of New Highway 7 (Bartlett, 1978).

EPA-287 (Cin.)
(4-76)

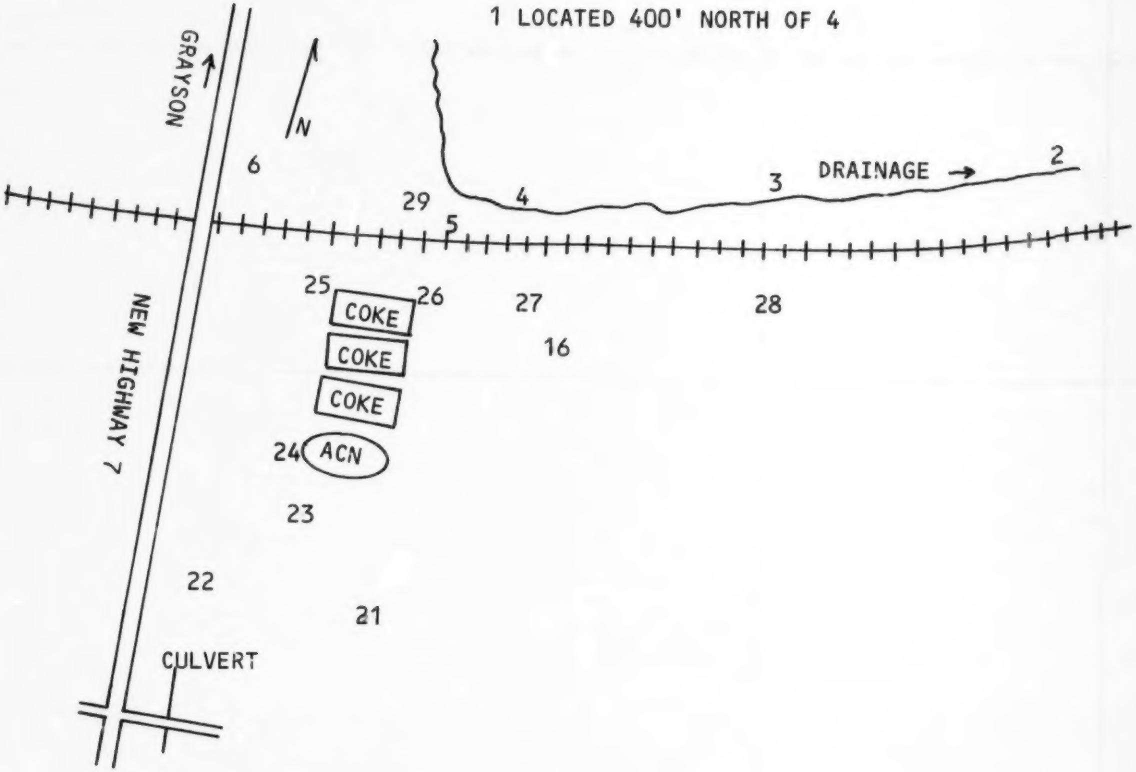

1 LOCATED 400' NORTH OF 4
GRAYSON
N
6
29
5
4
3
DRAINAGE →
2
25
26
27
28
COKE
COKE
COKE
16
24
ACN
23
NEW HIGHWAY 7
22
21
CULVERT

Figure 6b. Numbered soil sampling locations in spill areas (Bartlett, 1978).

TYPING GUIDE SHEET
EPA-287 (Cin.)
(4-76)

TABLE 12. ACRYLONITRILE LEVELS IN SURFACE SOIL SAMPLES[1] (STEWART LABORATORIES INC, IN BARTLETT, 1978)

Sample Number	Acrylonitrile levels in ppm	Sample Number	Acrylonitrile Levels in ppm
1	ND	30	41.6
2	0	31	1,940
3	0	32	14
4	0	33	9.9
5	54	34	20
6	65.9	35	21.3
7	0	36	0
8	60	37	8.1
9	26	38	10.2
10	0	39	0
11	0	40	0
12	0	41	0
13	0	42	0
14	0	43	1,480
15	30	44	4,250
16	0	45	105
17	ND	46	20
18	461	47	1,160
19	ND	48	ND
20	ND	49	ND
21	0	50	ND
22	22	51	ND
23	0	52	20.7
24	0	53	27.3
25	31	54	ND
26	221	55	ND
27	0	56	15,000
28	0	57	340
29	660	58	35.7
		59	17.6

[1] Sample locations in Figures 6a and 6b.

[2] ND -- No data

TABLE 13. ACRYLONITRILE LEVELS IN SOIL CORES (STEWART LABORATORIES INC. IN BARTLETT, 1978)

Sample Number	Soil Soil Depth (centimeters)	Samples Soil type	Percent Moisture	Acrylonitrile Levels (ppm)	
				As Received	Dry Weight
5	Surface	ice, disturbed clay	28.4	54.1	75.6
6	Surface	moist clay	27.8	47.6	65.9
7	Core	clay	20	2	2.5
8	0-20	sandy	32	60.8	89.9
8	20-36	clay	25	2	2.7
8	36-48	clay	24.6	2	22.7
9	0-18	topsoil	25.4	2	2.7
9	18-30	clay	19.8	2	2.5
9	30-41	hard clay	21.0	2	-
15	0-15	topsoil	20.8	30.0	37.9
22	0-15	soil core & oil	35.2	20.0	30.7
25	Surface	loose soil & coal	30.8	3.1	4.5
26	Surface	topsoil	17.2	221.0	274.0
30	0-8	topsoil	37.8	41.6	66.9
31	0-10	topsoil	41.6	1,940	3,320
32	0-13	burned topsoil	20.6	19	23.9
32	13-25	clay	25.6	2	2.7
32	25-36	clay	20.0	2.3	2.9
33	0-15	top burned	42.4	9.9	17.2
33	15-28	dark topsoil	27.0	145	199
33	28-43	top & clay	26.2	1,140	1,350
33	43-58	clay	19.4	636	789
34	0-15	top burned	29.8	20	28.5
34	15-33	dark clay	20.4	67	84.2
34	33-58	yellow clay	20.0	124	155
35	Surface	disturbed soil	43.8	21.3	37.9
38	0-10	frozen soil	27.4	10.2	14.0
38	10-20	loam	22.0	2	2.5
38	20-30	loam	20.0	2	2.5
43	0-13	topsoil	35.4	1,480	2,290
43	13-25	clay	27.2	165	227
43	25-36	hard clay	23.6	58	75.9
43	36-46	hard clay	24.8	40.5	53.9
50	152-168	liquid at bottom of hole	11.2	49,300	-
51	0-30	rich and soil	11.2	282	318
51	51-69	clay and sand	26.8	2,200	3,010
51	69-91	gray clay	18.6	744	914
51	91-102	clay	28.0	38.3	53.2
56	Surface	disturbed topsoil	29.2	15,000	21,200

PHENOL SPILL, SLABTOWN, MARYLAND

Background of Spill

On June 27, 1972, phenol was spilled as a result of derailment of a Western Maryland Railway freight train. Details of this spill are presented in Table 14. A shift of steel castings in a gondola car caused the 11-car derailment. Three of the cars were tankers carrying phenol. When the derailment occurred, two of the tank cars ruptured, spilling 94,635 liters of phenol. A topographical map, in Figure 7, shows the steep contour of the land in the spill area. The spilled phenol flowed down the steep embankment contaminating a pond, Trimble Spring, and a creek, Jennings Run, located at the bottom of the hill. It was estimated that 4,732 liters of phenol initially entered the creek and the remaining amount seeped into the soil (Ramsey and MacCrum, 1974). A more detailed illustration of the spill area is presented in Figure 8.

Climate of Spill Area

The average weather conditions in the area of Slabtown, Maryland are presented in Table 15. The wettest months of the year are from May to August, with about 10 cm of rain per month. The months with the highest winds are February through April. Weather conditions following the spill are presented in Table 16. Heavy rainfall occurred on the second and third day after the spill. The two months following the spill had below average levels of rainfall.

Geology of Spill Area

The soil in the spill area is a Buchannon type or a very stony loam. The 0-18 cm layer is a gravelly loam and 18-24 cm is a gravelly clay loam. The permeability of the soil is 1.5-15 cm/hour. The pH ranges from 5.0-5.5.

Response to the Spill

Shortly after the spill occurred, it was observed that phenol was leaching out of the soil into Jennings Run. Since Maryland State law prohibits discharge of toxic substances into waterways, the State required the railroad to reduce the leaking of phenol into Jennings Run. Several alternatives were evaluated for treating the spill. Finally, it was decided that the best solution to the problem would be a carbon filtration system. A trench or collection channel was made to hold the contaminated runoff from the phenol containing embankment. A 3.4 m x 3.7 m x 3.4 m box was constructed to hold 4.07 m^3 (144 ft^3) of gravel and 2.83 m^3 (100 ft^3) of granular activated carbon. A gravity flow system was used with the collection channel feeding into the top of the box and the effluent feeding into Jennings Run. The location of the box is illustrated in Figure 8.

Treatment was initiated during the week of 21 July and excellent removal of the phenol was accomplished. The activated carbon had to be changed approximately every 60 days. Due to channelization, the filtration system was modified in the spring of 1973 to feed the influent to the bottom of the chamber. By 17 May 1973, the system was only operated when the phenol levels

TABLE 14. BACKGROUND OF PHENOL SPILL, SLABTOWN, MARYLAND

Chemical Spilled	Phenol
Class of Material	Poison B
Amount Spilled	94,635 liters
How Occurred	Derailment
Date	June 27, 1972
Time	-----
Location	Slabtown, Maryland
On-site Spill Coordinator	W. Lawrence Ramsey Maryland Water Resources Administration Maryland

---- data not available

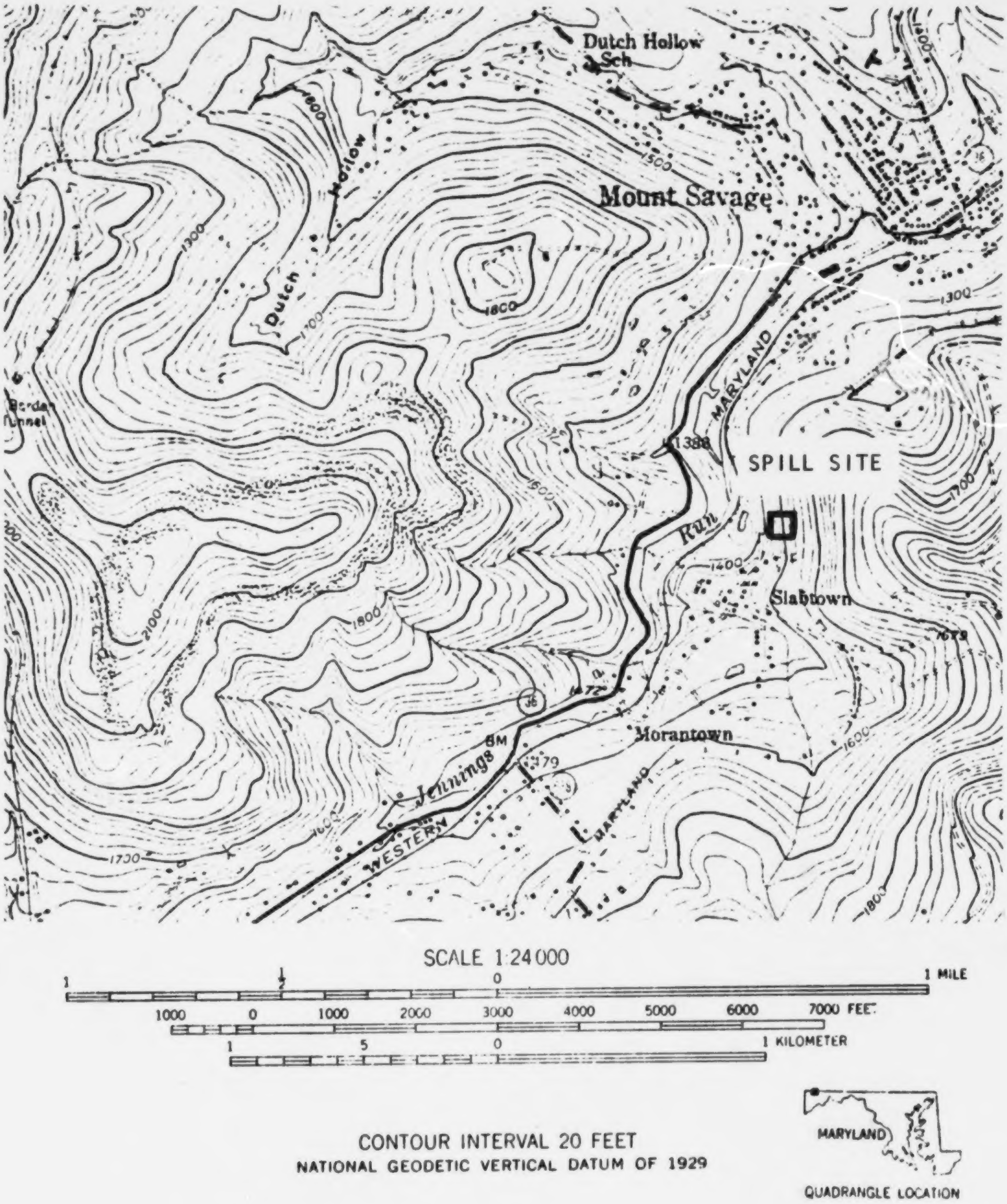

Dutch Hollow Sch
Mount Savage
Dutch
Hollow
Borden Tunnel
SPILL SITE
Slabtown
Morantown
Jennings
Run
MARYLAND
WESTERN
MARYLAND
BM
1388
1800
1300
1700
1600
2100
1500
1400
36
SCALE 1:24000
1
½
0
1 MILE
1000
0
1000
2000
3000
4000
5000
6000
7000 FEET
1
5
0
1 KILOMETER
CONTOUR INTERVAL 20 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929
MARYLAND
QUADRANGLE LOCATION

Figure 7. Topography of phenol spill area, Slabtown, Maryland (U.S. Geological Survey, 1974).

BEGIN FIRST LINE OF TEXT HERE
TYPING GUIDE SHEET
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD, BEGIN SECTIONS HERE

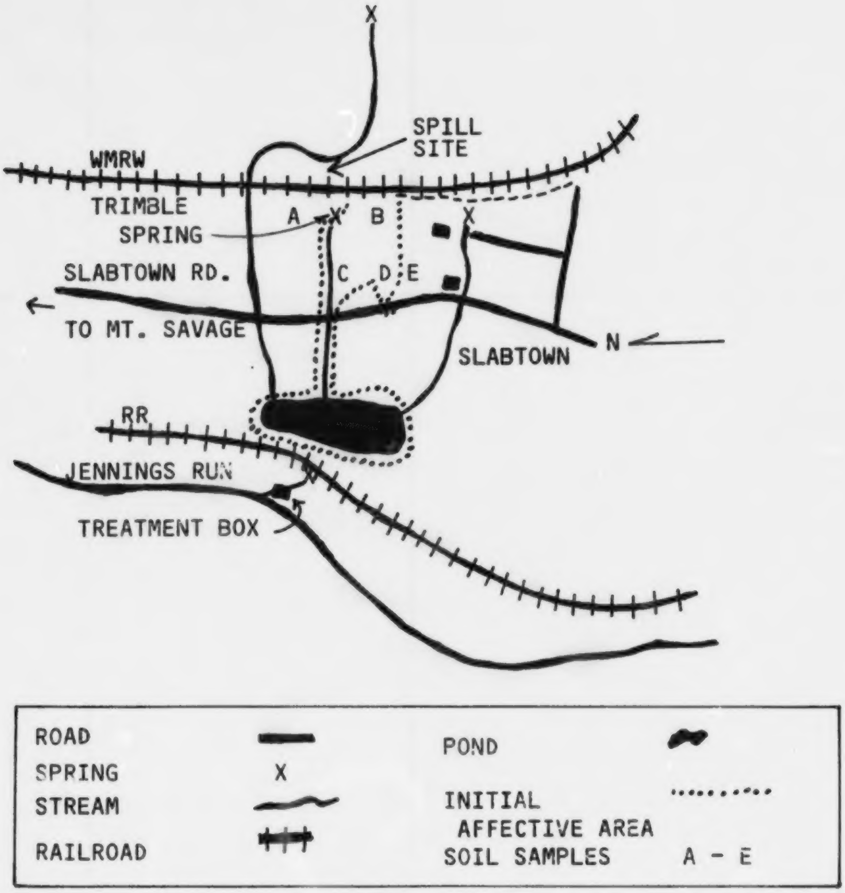

X
SPILL SITE
WMRW
TRIMBLE SPRING
A
X
B
X
SLABTOWN RD.
C
D
E
TO MT. SAVAGE
SLABTOWN
N
RR
JENNINGS RUN
TREATMENT BOX
ROAD
SPRING X
STREAM
RAILROAD
POND
INITIAL AFFECTIVE AREA
SOIL SAMPLES A - E

Figure 8. Detailed map of phenol spill site and sampling locations (Ramsey and MacCrum, 1974).

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-287 (Cin.) (4-76)

TABLE 15. WEATHER CONDITIONS OF SLABTOWN, MARYLAND (RUFFNER AND BLAIR, 1978)

Month	Average Temperature °C (°F)	Average Precipitation cm (inches)	Average Wind Speed kmph (mph)
January	-0.6 (30.8)	8.0 (3.16)	12.6 (7.9)WNW
February	-0.3 (31.4)	6.3 (2.50)	17.2 (10.8)NW
March	3.3 (38.1)	10.0 (3.95)	17.9 (11.2)WNW
April	9.8 (49.8)	9.0 (3.57)	17.6 (11.0)WNW
May	15.5 (60.0)	11.0 (4.35)	15.5 (9.7)WNW
June	19.8 (67.8)	11.0 (4.35)	14.0 (8.8)WNW
July	21.8 (71.3)	9.4 (3.71)	13.1 (8.2)W
August	21.0 (69.9)	10.3 (4.08)	13.2 (8.3)W
September	17.5 (63.5)	8.1 (3.19)	13.4 (8.4)S
October	11.8 (53.4)	7.9 (3.13)	14.4 (9.0)NW
November	5.3 (41.7)	6.6 (2.61)	12.1 (7.6)WNW
December	-0.05(31.9)	7.2 (2.86)	15.2 (9.5)WNW
Yearly Average	10.4 (50.8)	105.7 (41.64)	15.2 (9.5)W

EPA Form 2350-4 (4-80)
(PREVIOUSLY FIN. EPA FORM 37)
TYPING GUIDE SHEET

TABLE 16. WEATHER CONDITIONS AFTER THE SPILL IN SLABTOWN, MARYLAND (RUFFNER AND BLAIR, 1978)

Date	Temperature Range °C	(°F)	Precipitation cm	(inches)
June 27	11.6-26.6	(53-80)	0.0	(0.0)
June 28	13.3-27.2	(56-81)	0.0	(0.0)
June 29	13.3-27.2	(56-81)	3.1	(1.24)
June 30	14.4-29.4	(58-85)	1.6	(0.64)
July 1	14.4-31.1	(58-88)	0.0	(0.0)
July 2	14.4-31.6	(58-89)	0.0	(0.0)
July 3	18.3-31.6	(65-89)	0.07	(0.03)
July 4	15.0-26.1	(59-79)	0.0	(0.0)
July 5	13.3-24.4	(56-76)	1.8	(0.74)
July 6	12.2-20.0	(54-68)	0.1	(0.07)
July7	8.3-24.4	(47-76)	0.0	(0.0)
July 8	10.5-25.5	(51-78)	0.0	(0.0)
July 9	10.5-27.7	(51-82)	0.0	(0.0)
July 10	14.4-33.8	(58-93)	0.0	(0.0)
June Total			23.9	(9.43)
July Total			5.4	(2.13)
August Total			5.1	(2.02)

in the influent exceeded 10 ppm. During the summer of 1973, low levels of phenol were found in the influent and on October 3, 1973, the system was shut down.

Environmental Levels of the Spilled Material

Phenol levels in Trimble Spring were extremely high. Phenol concentrations for the four days that the spring was sampled were:

Date	Phenol Levels (ppm)
7/22	1,280
8/22	1,500
8/28	1,500
9/09	1,350

Water from Trimble Spring was fed into the collection channel and was treated by the carbon filtration system.

The effectiveness of the carbon filtration system is illustrated in Table 17. Initially the system worked very well and removed over 99% of the phenol from the water. Influent levels, during the first 3 months, ranged from 144-1130 ppm and effluent levels ranged from 0.25-160 ppm. However, channeling occurred through the filtration system resulting in only 8.6% phenol reduction on 18 October. The chaneling problem was corrected by reversing the flow and pumping up through the bottom of the system. By March, 1973, phenol levels in the influent were less than 60 ppm and by June levels were less than 20 ppm. Phenol levels in Jennings Run were reduced from 1-2 ppm in October, 1972, to less than 0.5 ppm in June-August, 1973.

Soil cores were collected on 15 July 1972, and 3 April 1973. The phenol levels in the soil cores are presented in Table 18. Sample locations are shown in Figure 8. The initial phenol concentration in the top 17 cm of soil ranged from 415 to 2757 ppm. Analysis of the soil samples indicated that the phenol had penetrated the soil to a depth of more than 61 cm. In April, 1973, phenol levels in the top 17 cm of the soil were reduced to the 30 ppm range. The reduction of the phenol levels in the soil paralleled the reduced phenol levels in the influent to the carbon filtration unit.

Biological Effects of the Spill

When the phenol spill occurred, all plant life in the spill area was chemically burned (Ramsey and MacCrum, 1974). It is assumed that the soil flora would also have been destroyed in the area of the spill. By May, 1973, the phenol concentration had been reduced to a sufficiently low level that microbial degradation of the remaining phenol could occur (Ramsey and MacCrum, 1974). Ramsey (personal communication, 1979) stated that after three years the land area had recovered from the phenol spill.

EPA Form 2250-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 257)
TYPING GUIDE SHEET

TABLE 17. PHENOL LEVELS THROUGH TREATMENT SYSTEM AND JENNINGS RUN (IN PPM) (NATURAL RESOURCES DEPARTMENT, CUMBERLAND, MARYLAND)

Date	Influent	Effluent	Percent Removal	Jennings Run (Downstream) for an Effluent
7/25/72	144	1.9	98.7	-
7/25/72	156	.25	99.8	-
7/27/72	162	.4	99.8	-
8/01/72	-	8.4	-	-
8/04/72	490	.7	99.9	-
8/08/72	940	.5	99.9	-
8/11/72	-	20.0	-	-
8/17/72	740	22.0	97.0	-
8/22/72	740	160.0	78.4	-
8/30/72	500	13.0	97.4	-
10/03/72	850	65.0	92.4	-
10/11/72	1,130	113.0	90.0	-
10/18/72	580	530.0	8.6	2.1
10/27/72	720	-	-	-
10/30/72	580	1.8	99.7	-
11/02/72	1,080	113.0	89.5	-
11/10/72	550	58.8	89.5	1.8
3/05/73	55	60.0	0.0	1.5
3/19/72	25	30.0	0.0	0.7
4/02/73	20	30.0	0.0	.46
4/18/73	30	-	-	.5
4/19/73	30	30.0	0.0	.5
5/03/73	26	.1	99.6	.2
5/07/73	15	1.2	92.0	.2
5/14/73	7	7.0	0.0	.2
5/21/73	-	7.0	-	.4
5/23/73	-	7.0	-	.25
5/25/73	-	7.2	-	.4
5/29/73	11	-	-	.3
6/01/73	6	-	-	.3
6/04/73	4	-	-	.2
6/08/73	7	-	-	.3
6/11/73	8	-	-	.3
6/15/73	18.8	-	-	.42
6/16/73	16	.7	95.6	.6
6/20/73	17.5	.7	96.0	.3
6/22/73	11	.13	98.8	.1
6/25/73	15.8	.6	96.2	.2
6/27/73	16.5	.8	95.2	.22
6/29/73	21	.6	97.1	.38
7/02/73	9	.8	91.1	.15
7/06/73	14	.75	94.6	.25
7/09/73	12	.8	93.3	.25

(continued)

EPA Form 2350-1 (4-80)
(PREVIOUSLY CIN. EPA FORM 287)
TYPING GUIDE SHEET

TABLE 17. (continued)

Date	Influent	Effluent	Percent Removal	Jennings Run (Downstream) for an Effluent
7/11/73	12	.78	93.5	.21
7/13/73	11.5	.7	93.9	.17
7/16/73	9	.65	92.8	.12
7/23/73	5	.57	88.6	.2
7/30/73	2.3	.8	65.2	.2
8/02/73	6.3	-	-	.5
8/06/73	.5	-	-	.2
8/09/73	1.25	-	-	.27
8/13/73	2.25	-	-	.3

- no analysis

TABLE 18. PHENOL LEVELS IN SOIL SAMPLES (NATURAL RESOURCES DEPARTMENT, CUMBERLAND, MARYLAND)

Location	Depth		Phenol Concentrations (ppm)	
	cm	(inches)	Date Collected 7/15/72	Date Collected 4/3/73
A	Surface		1.2	1.2
	15.0	(6)	.9	ND
	30.0	(12)	1.4	ND
B	2.5-17.7	(1-7)	2,727	31.6
	25.4-38.1	(10-15)	69	6.8*
	40.6-55.8	(16-22)	1.4	9.4*
	55.8-71.1	(22-28)	5.4	ND
C	2.5-17.7	(1-7)	434	32
	17.7-30.0	(7-12)	148	59*
	40.6-55.8	(16-22)	374	22.8*
	60.9-76.2	(24-30)	298	ND
D	2.5-17.7	(1-7)	415	31.1
	17.7-30.0	(7-12)	88	11.0*
	30.0-38.1	(12-15)	184	17.0*
	45.7-60.9	(18-24)	170	ND
E	Surface		1.2	16.2
			ND	46.3*
			ND	37.1*

* Depth not given

ND Not determined

ACRYLONITRILE SPILL, DAYTON, OHIO

Background of Spill

On 11 June 1974, a Chessie system freight train was derailed after hitting an obstruction on the tracks. A tank car containing acrylonitrile was punctured and caught fire. Details of the spill are summarized in Table 19. A contour map of the spill area is presented in Figure 9. The spill occurred on flat land in a relatively low population area.

Climate of Spill Area

The average weather conditions for the Dayton, Ohio area are presented in Table 20. Typically, the months of March through July have the highest precipitation. The month of June, when the spill occurred, is typically the wettest month. The highest winds in the area occur in the late winter and early spring. The wind direction is primarily from the south-south-west.

Geology of Spill Area

The soil type is a Miamian-celina association with fine textured and well drained soils. The Fox-Urban land complex soils are well drained and are underlaid by calcareous sand and gravel at a depth of 61 to 107 cm (24 to 42 inches). Because of this layer, permeability is rapid and contamination of ground water can occur (USDA, 1976).

The ground at the spill site is underlaid by valley train deposits. The water table is at a depth of 3-6 m (10-20 feet), overlaid by porous loam and mixed gravel/clay layers.

Response to Spill

A detailed map of the spill site is presented in Figure 10. The fire that occurred after the spill, was put out and the area was sprayed to prevent reignition. Therefore, large pools of acrylonitrile/water mixture were present in the area.

The day after the spill, 12 June, a pump car arrived to remove the remaining acrylonitrile from the tank car. About 44,289 liters (11,700 gallons) of the acrylonitrile were recovered. The remaining 31,642 liters (8,630 gallons) were burned or lost to the environment. On 13 June, samples of the pools of the spilled material were collected and a geologist checked the site. The results of the tests, as shown below, indicated that very high levels of acrylonitrile were present in the area:

	Acrylonitrile Before Treatment
Puddle north side of tracks	2,203 ppm
Puddle south side of tracks	7,231 ppm
Pool in woods	82-471 ppm

TABLE 19. BACKGROUND OF ACRYLONITRILE SPILL DAYTON, OHIO

Chemical Spilled	Acrylonitrile
Class of Material	Flammable liquid
Amount Spilled	31,642 liters
How Occurred	Derailment
Date	June 11, 1974
Time	2:52 p.m.
Location	10 kilometers east of Dayton, Ohio
On-site Spill Coordinator	Mr. Ken Harsh Ohio EPA Columbus, Ohio

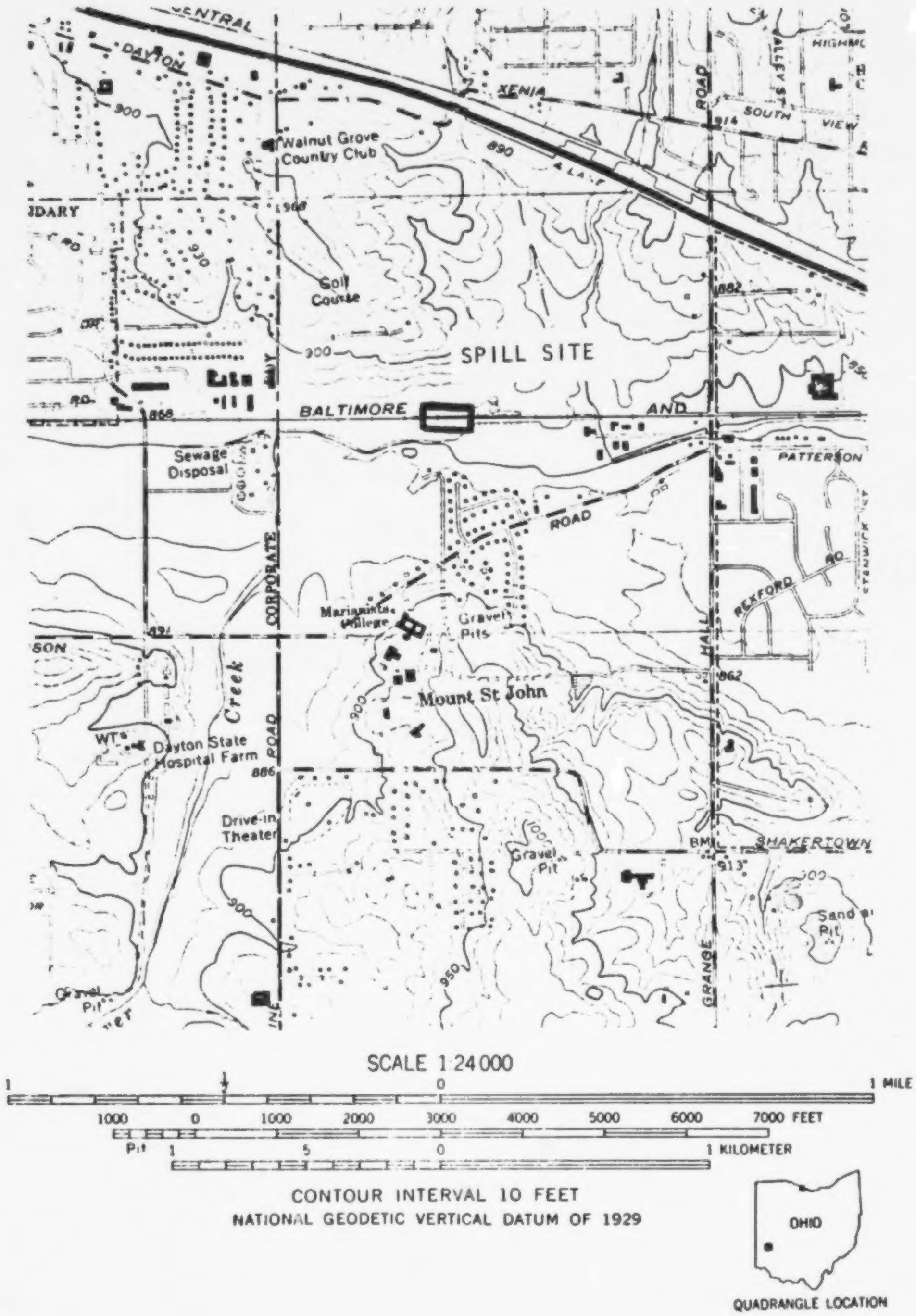
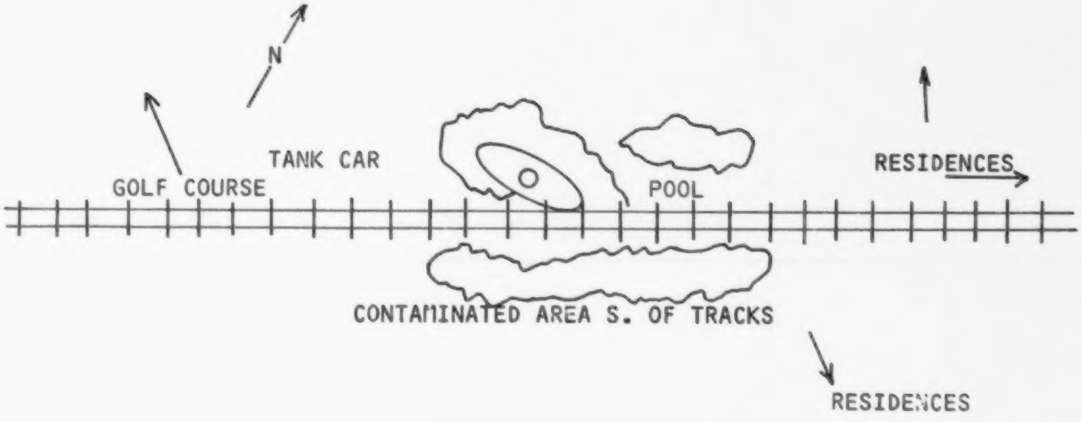

CENTRAL
DAYTON
XENIA
SOUTH
VIEW
HIGHMO
ROAD
Walnut Grove Country Club
890
900
910
BOUNDARY
Golf Course
SPILL SITE
882
BALTIMORE
AND
868
Sewage Disposal
PATTERSON
ROAD
REXFORD RD
CORPORATE
Marianist College
Gravel Pits
Creek
Mount St John
862
HALL
WT
Dayton State Hospital Farm
886
ROAD
Drive-in Theater
Gravel Pit
BM
SHAKERTOWN
913
Sand Pit
950
GRANGE
Gravel Pit
SCALE 1:24 000
1
0
1 MILE
1000
0
1000
2000
3000
4000
5000
6000
7000 FEET
1
5
0
1 KILOMETER
CONTOUR INTERVAL 10 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929
OHIO
QUADRANGLE LOCATION

Figure 9. Topography of acrylonitrile spill area, Dayton Ohio (U.S. Geological Survey, 1974)

TABLE 20. WEATHER CONDITIONS, DAYTON, OHIO (RUFFNER AND BLAIR, 1978)

Month	Average Temperature		Average Precipitation		Average Wind Speed		
	°C	(°F)	cm	(inches)	kmph	(mph)	
January	-1.2	(29.7)	7.5	(2.96)	18.8	(11.8)	S
February	-0.3	(31.4)	5.3	(2.11)	19.3	(12.1)	WNW
March	4.3	(39.8)	8.2	(3.24)	19.8	(12.4)	WNW
April	10.2	(50.5)	7.7	(3.07)	19.2	(12.0)	SSW
May	16.1	(61.0)	8.9	(3.54)	16.1	(10.1)	SSW
June	21.6	(70.9)	9.9	(3.90)	14.5	(9.1)	SSW
July	23.8	(75.0)	8.3	(3.29)	12.8	(8.0)	SSW
August	22.7	(72.9)	7.2	(2.86)	12.0	(7.5)	SSW
September	19.3	(66.9)	7.1	(2.80)	13.2	(8.3)	SSW
October	12.8	(55.1)	5.8	(2.30)	14.4	(9.0)	SSW
November	5.5	(41.9)	6.6	(2.61)	18.2	(11.4)	S
December	-0.1	(31.7)	6.2	(2.47)	18.4	(11.5)	SSW
Yearly Average	11.2	(52.2)	89.2	(35.15)	16.4	(10.3)	


N
TANK CAR
GOLF COURSE
POOL
RESIDENCES
CONTAMINATED AREA S. OF TRACKS
RESIDENCES

SCALE 1" = 38.1 METERS

Figure 10. Detailed map of spill site (Harsh, 1978).

It was determined that the spill presented a danger to the ground water supply in the area (Harsh, 1978).

The Ohio EPA decided to oxidize the acrylonitrile on site. This process was accomplished first by raising the pH above 10 with lime and then spraying sodium hypochlorite over the area. According to the reaction:

(1) $CN^- + HOCl \rightarrow CNCl + OH^-$

(2) $CNCl + 2OH^- \rightarrow CNO^- + Cl^- + H_2O$

(3) $2CNO^- + 3OCl^- + H_2O \rightarrow 2CO_2 + N_2 + 3Cl^- + 2OH^-$

On 15 June, 4,354 kg (9,600 pounds) of lime were applied to the contaminated areas and 635 kg (1,400 pounds) of sodium hypochlorite were sprayed on the areas by O & H Materials. Results of the treatment are shown below:

	Acrylonitrile After Treatment	Percent Removal
Puddle north side of tracks	62.5 ppm	97.1
Puddle south side of tracks	13.1 ppm	99.8
Pool in woods	24.0 ppm	90-96

The percent removal in the highly contaminated area was 97% or greater. Overall, acrylonitrile levels were reduced to the 13-63 ppm range.

Environmental Levels of Spill Material

Although the surface pools were heavily contaminated before clean-up, water samples of the wells in the area indicated no contamination of the water table.

Biological Damage to Area

Most of the damage to plants in the area was due to the fire. No other effects were noted (Harsh, personal communication, 1979).

NITRIC ACID SPILL, ESTILL, SOUTH CAROLINA

Background of Spill

In Estill, near the intersection of Route 3 and Route 321, there is a railroad crossing. On August 4, 1977, a truck carrying nitric acid was crossing the railroad tracks. While on the tracks, the driver noted a switch engine coming toward his trailer. The engine hit the end of the trailer, overturning the trailer. Details of the spill are presented in Table 21. A contour map of the spill area is shown in Figure 11.

TABLE 21. BACKGROUND OF NITRIC ACID SPILL ESTILL, SOUTH CAROLINA

Chemical Spilled	Nitric Acid
Class of Material	Corrosive Material
Amount Spilled	3,592.4 kg
How Occurred	Truck-train accident
Date	August 4, 1977
Time	3:00 p.m.
Location	Estill, South Carolina
On-site Spill Coordinator	Marshall Dixon and Karl Chandler South Carolina Department of Health and Environmental Control

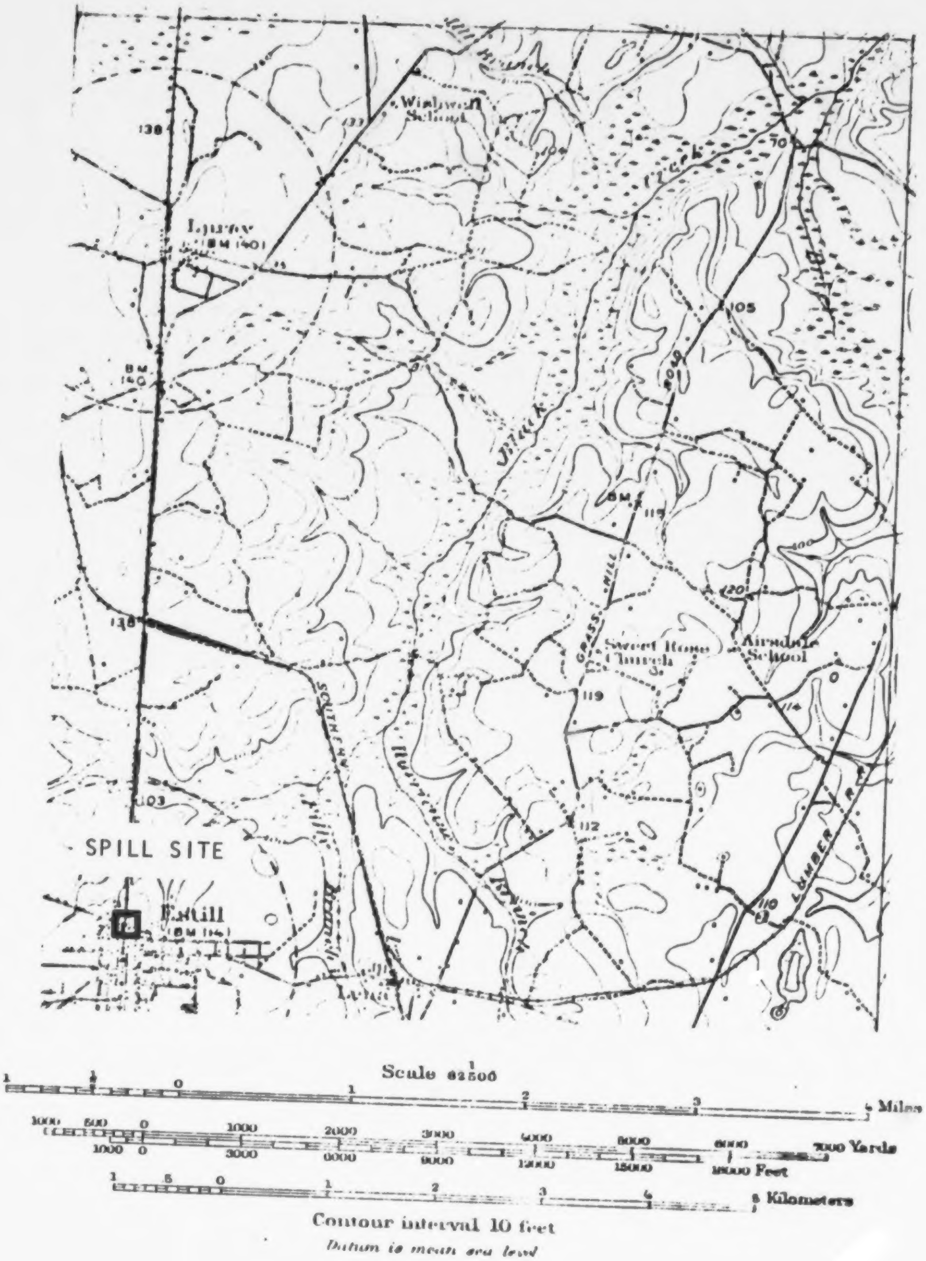

Luray
(BM 140)
SPILL SITE
Estill
(BM 114)
Sweet Home Church
School
Scale 1/62500
Miles
Yards
Feet
Kilometers
Contour interval 10 feet
Datum is mean sea level

Figure 11. Topography of nitric acid spill site, Estill, South Carolina (U.S. Department of Geological Survey, 1945)

Climate of Spill Area

The average weather conditions in Estill, South Carolina, are presented in Table 22. The month of the spill, August, is one of the wettest months of the year, with an average precipitation of 16.5 cm (6.49 inches). Winds, from March through August, are from the south and south-west. During the winter months, the winds are predominantly from the north and north-west.

Geology of Spill Area

The soil characteristics of the area are typically a Ruston sandy loam. The top soil has an average depth of 15 cm (6 inches) and is a gray to gray-brown sandy loam. The subsoil has a depth range from 38-61 cm (15-24 inches) and is made up of a reddish-yellow sandy loam and a reddish- yellow clay (Whitney, 1915).

Response to Spill

The on-site coordinators (OSC) arrived at the scene at 5:00 p.m., two hours after the spill. They found the tanker on its side leaking nitric acid from a pipe in the top of the tank. The fire department had been spraying water on the acid since 3:15 pm. The water/acid mixture was flowing into a drainage ditch along the tracks. The OSC had the ditch dammed to limit the soil contamination. At midnight, the trailer was righted and two truckloads of lime were applied to the road and in the ditch.

Clean-up operations were started the next morning, 5 August. The upper 10 cm (4 inches) of topsoil were removed and deposited in the ditch so the contaminated water and soil could be uniformly neutralized with lime. The dirt was then hauled to a landfill. Forty to fifty truck loads were required to remove the soil. Forty-two truck loads of clean soil were used to fill in the spill area. The soil was then graded and reseeded. The cost of the clean-up was approximately $5,300.

Environmental Levels of Spilled Material

The trailer was leaking 67% nitric acid. The only measurement in the spill area was the acid/water mixture in the ditch. The pH of that mixture was 1.8.

Biological Damage to Area

Due to the low pH of acid/water mixture, all plant life in the spill area was chemically burned. Soil fauna in contact with the chemical were also chemically burned.

CAUSTIC SODA SPILL, DUFFEE, MISSISSIPPI

Background of Spill

An Illinois Central Gulf railroad train was involved in a 12-car derailment in Duffee, Mississippi on July 4, 1977. One car containing caustic soda ruptured when the derailment occurred, releasing its contents, 60,567 liters (16,000 gallons). Another car, also containing caustic soda lost 5,678 liters (1,500

TABLE 22. WEATHER CONDITIONS, ESTILL, SOUTH CAROLINA (RUFFNER AND BLAIR, 1978)

Month	Average Temperature °C	(°F)	Average Precipitation cm	(inches)	Average Wind Speed kmph	(mph)	
January	10.3	(50.6)	6.5	(2.57)	14.7	(9.2)	SW
February	11.1	(52.0)	8.8	(3.49)	16.4	(10.3)	NNE
March	14.1	(57.4)	9.8	(3.87)	16.6	(10.4)	SSW
April	18.4	(65.2)	8.6	(3.41)	16.1	(10.1)	SSW
May	22.5	(72.6)	9.6	(3.78)	14.2	(8.9)	S
June	26.0	(78.9)	13.0	(5.15)	13.6	(8.5)	S
July	27.0	(80.7)	17.2	(6.78)	12.8	(8.0)	SW
August	26.8	(80.3)	16.4	(6.49)	11.8	(7.4)	SW
September	24.4	(76.0)	11.4	(4.49)	12.8	(8.0)	NNE
October	19.1	(66.5)	7.4	(2.92)	12.9	(8.1)	NNE
November	13.6	(56.6)	5.7	(2.25)	13.1	(8.2)	N
December	10.0	(50.0)	6.9	(2.74)	13.9	(8.7)	NNE
Yearly Average	18.6	(65.6)	123.0	(48.44)	14.0	(8.8)	

gallons) when rerailing of the car was in progress. Details of the spill are presented in Table 23. A contour map, with the location of the spill is presented in Figure 12.

Climate of Spill Area

The weather conditions for the Duffee, Mississippi area are presented in Table 24. Although the greatest precipitation of the year occurs during the winter months, July, the month of the spill, also had high amounts of rainfall. Average wind speeds during the summer months range from 9.7-11 kmph (5.8-6.7 mph).

Geology of Spill Area

The soil is a bibb type. These soils are on flood plains and are poorly drained, strongly acid silt loam or sandy loam soils. The pH is 5.1-5.5 and the permeability is 2-6.2 cm (0.8-2.50 inches)/hour (USDA, 1960).

Response to Spill

Initially, the railroad treated the spill site by flushing with water and removing the soil to a disposal pit (Dickson, personal communication, 1977). Since no water bodies were affected, the railroad did not treat the area further.

However, one month later, the railroad was notified of resident complaints of fumes and high pH water. They were instructed by the Mississippi Air and Water Pollution Control Commission to further treat the spill site in early August. The railroad applied 2,721 kg (6,000 pounds) of alum to reduce the pH of the soil.

Environmental Levels of Spilled Material

After treatment with alum, soil pH levels were measured in the spill area (Table 25). The pH levels indicated that the treatment was fairly successful in reducing the high pH.

Biological Damage to Area

Harper (personal communication, 1977) noted that damage to vegetation and drainage contours had occurred. It is probable that soil fauna were also removed from the spill area. However, upon lowering of the pH, recolonization of the area should occur.

FORMALIN SPILL, RENSSELAER COUNTY, NEW YORK

Background of Spill

Details of the spill are presented in Table 26. On June 6, 1972, a tire blew out on a chemical truck in Rensselaer County, New York. The truck rolled down a 25 foot embankment and ruptured spilling 18,927 liters (5,000 gallons) of 40% formaldehyde solution. The spill occurred on a hill in the median of the highway several hundred feet from a stream. The stream feeds into Roundtop Pond. A contour map of the area and a detailed map of the spill site are presented in Figures 13 and 14.

TABLE 23. BACKGROUND OF CAUSTIC SODA SPILL DUFFEE, MISSISSIPPI

Chemical Spilled	Liquid caustic soda - NaOH
Class of Material	Corrosive material
Amount Spilled	66,244.7 liters
How occurred	Derailment
Date	July 4, 1977
Time	3:10 a.m.
Location	Duffee, Mississippi
On-site Spill Coordinator	John W. Harper Air and Water Pollution Control Commission Jackson, Mississippi

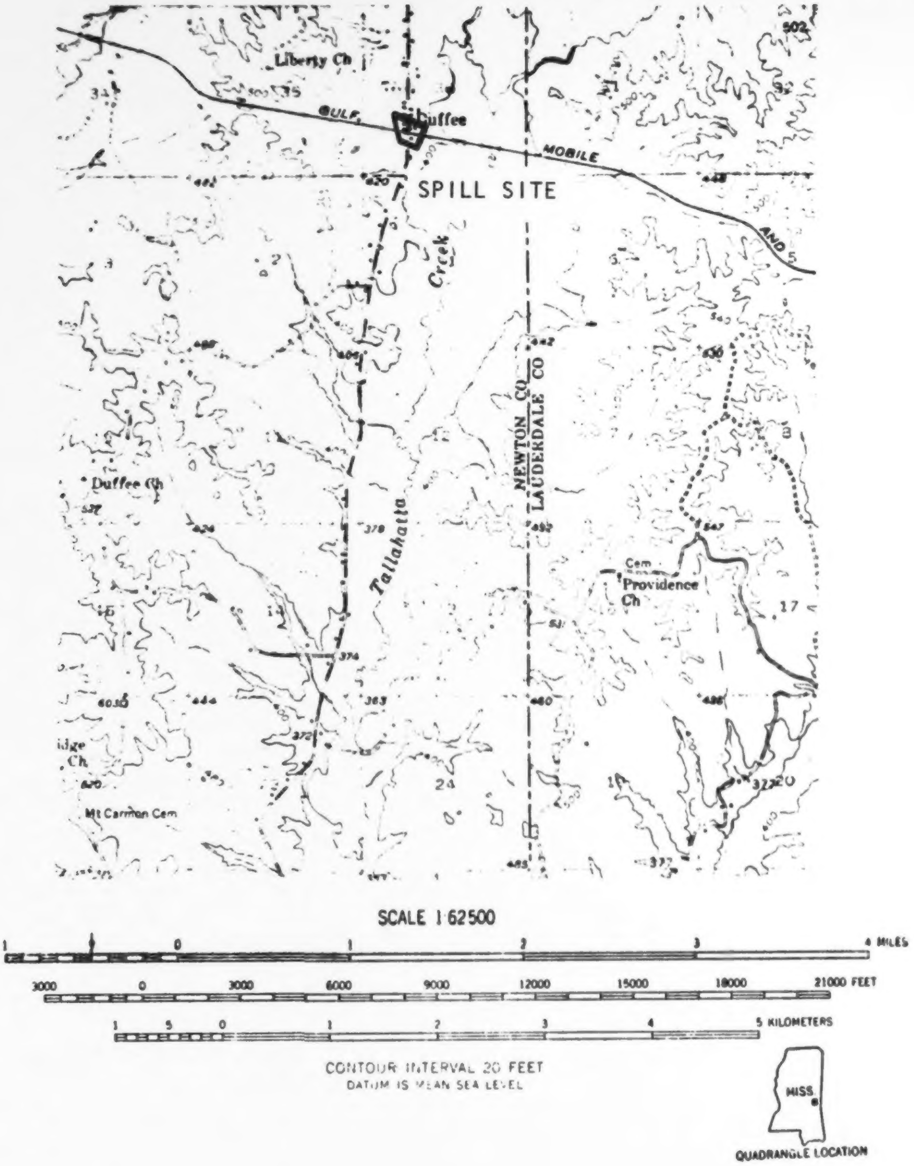

Liberty Ch
Duffee
GULF, MOBILE AND
SPILL SITE
Tallahatta Creek
NEWTON CO
LAUDERDALE CO
Duffee Ch
Cem
Providence Ch
Mt Carmon Cem
SCALE 1:62500
MILES
FEET
KILOMETERS
CONTOUR INTERVAL 20 FEET
DATUM IS MEAN SEA LEVEL
MISS.
QUADRANGLE LOCATION

Figure 12. Topography of caustic soda spill site, Duffee, Mississippi (U.S. Geological Survey, 1957)

TABLE 24. WEATHER CONDITIONS, DUFFEE, MISSISSIPPI (RUFFNER AND BLAIR, 1978)

Month	Average Temperature °C	(°F)	Average Precipitation cm	(inches)	Average Wind Speed kmph	(mph)
January	9.3	(48.9)	14.0	(5.53)	14.5	(9.1)
February	10.5	(50.9)	12.2	(4.84)	14.5	(9.1)
March	14.0	(57.3)	15.0	(5.93)	15.3	(9.6)
April	18.0	(64.5)	11.3	(4.47)	14.7	(9.2)
May	22.2	(72.1)	10.2	(4.03)	11.8	(7.4)
June	26.3	(79.4)	8.8	(3.47)	10.0	(6.3)
July	27.5	(81.5)	12.8	(5.05)	9.9	(6.2)
August	27.3	(81.3)	7.6	(3.00)	9.2	(5.8)
September	24.5	(76.1)	4.9	(1.93)	10.7	(6.7)
October	18.9	(66.1)	4.3	(1.70)	10.5	(6.6)
November	12.6	(54.8)	8.7	(3.43)	12.6	(7.9)
December	9.7	(49.5)	14.0	(5.54)	13.9	(8.7)
Yearly Average	18.4	(65.2)	125.6	(49.47)	12.3	(7.7)

TABLE 25. SOIL pH LEVELS AFTER TREATMENT WITH ALUM (DICKERSON, 1977)

Location	pH
South of Track 18.3 m from crossing 2.3 m from track	8.1
South of Track 9.1 m from crossing 9.1 m from track	8.1
South of Track 45.7 m from crossing 9.1 m from track	8.2
North of Track 21.3 m from crossing 21.3 m from track	6.8
North of Track 45.7 m from crossing 10.7 m from track	6.8
North of Track 56.4 m from crossing 19.8 m from track (over disposal pit)	8.9
North of Track 61 m from crossing 9.1 m from track	8.2

TABLE 26. BACKGROUND OF FORMALDEHYDE SPILL RENSSELAER COUNTY, NEW YORK

Chemical Spilled	Formaldehyde
Class of Material	Combustible Liquid
Amount Spilled	19,000 liters
How Occurred	Tire failure accident
Date	June 6, 1972
Location	Berkshire Section of I-90, Rensselaer County, New York
On-site Spill Coordinator	New York State Health Department

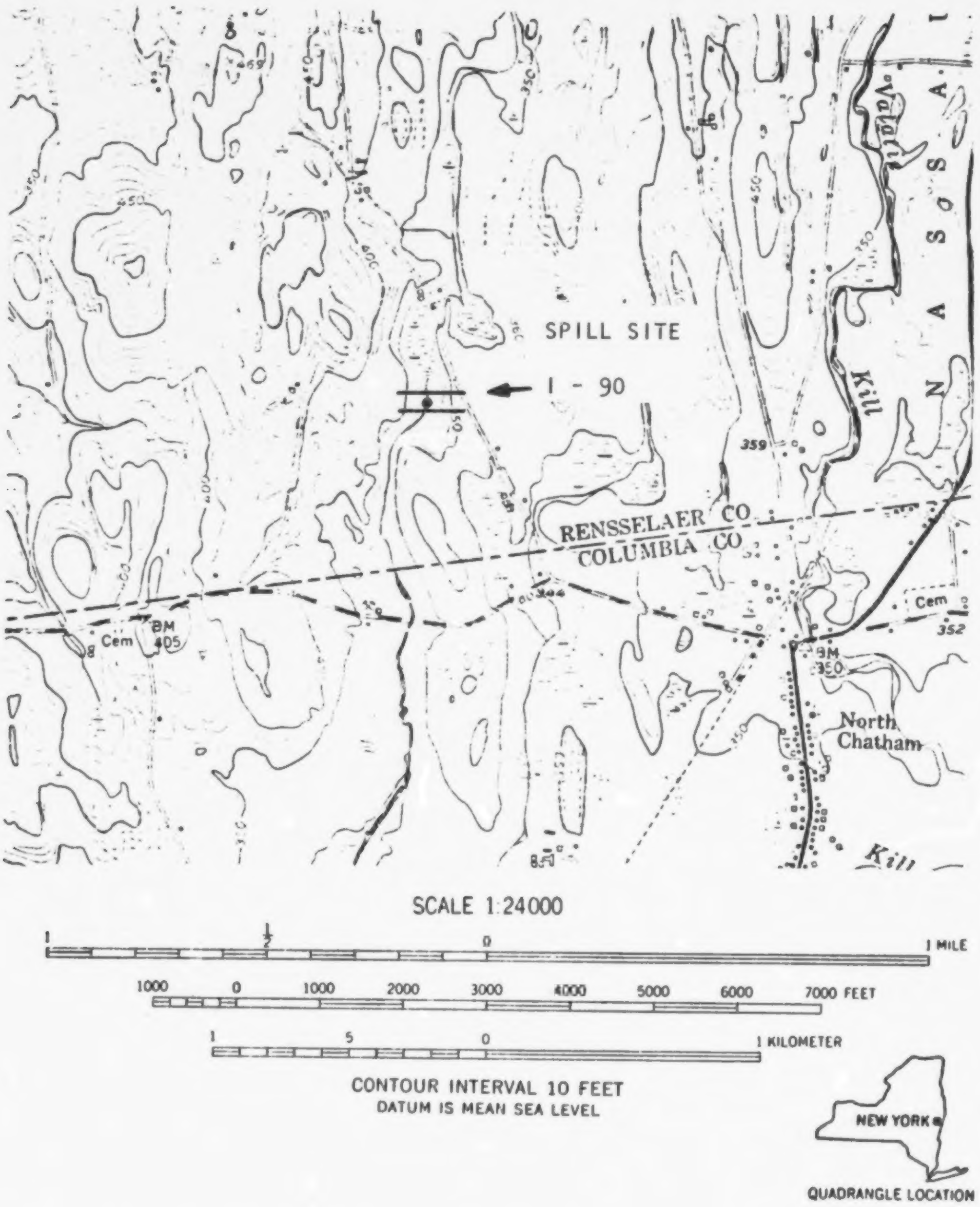

SPILL SITE
I - 90
RENSSELAER CO
COLUMBIA CO
Valatie
Kill
NASSAU
359
Cem
BM
405
Cem
352
BM
350
North Chatham
Kill
SCALE 1:24000
1 ½ 0 1 MILE
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 5 0 1 KILOMETER
CONTOUR INTERVAL 10 FEET
DATUM IS MEAN SEA LEVEL
NEW YORK
QUADRANGLE LOCATION

Figure 13. Topography of formaldehyde spill site, Rensselaer New York (U.S. Geological Survey, 1971)

Climate of Spill Area

The average weather conditions in the spill area are presented in Table 27. The months of May, June and July receive an above average amount of precipitation. Winds from May to December are moderate and from the south. The weather conditions immediately after the spill are summarized in Table 28. June, 1972, was an above average month for precipitation with 17.4 cm (6.84 inches) of rain. This amount is 9.1 cm (3.59 inches) over the normal amount. Rain occurred the day of the spill, June 6th, and continued through June 10th.

Geology of Spill Area

The topsoil in the area is a dark-brown silt-loam which persists to a depth of 18-20 cm (Latimer, 1932). The subsoil is made up of a yellowish-brown sandy loam. A marsh and stream are located at the bottom of the contaminated slope. The stream feeds into Roundtop Pond (See Figure 14).

Response to Spill

The formaldehyde was adsorbed by the porous sandy loam soil at the spill site. Because of the adsorption, no toxic effects of the chemical were noted in the stream. Treatment or removal of the formaldehyde from the soil was determined not to be necessary. However, the area was monitored for formaldehyde levels for one year.

Environmental Levels of Spilled Material

Formaldehyde levels in the soil are presented in Table 29. The data indicate that very high levels of formaldehyde were present at depths of 15-30 cm (6-12 inches) shortly after the spill. However, three weeks later 80- 90% of the formaldehyde had evaporated, degraded or was washed deeper into the soil by the heavy rainfall. One year after the spill, 97-100% of the formaldehyde had been removed from the top 12 inches of the soil.

In contrast, marsh core sample, data shown in Table 30, indicate increased formaldehyde levels occurred over time. Formaldehyde levels in the ground water appeared to decrease after the spill (See Table 30). However, after one year, formaldehyde levels in the water were still relatively high. Thus, it appears that the formaldehyde was moving down the slopes and was slowly leaching into the creek.

Biological Damage to Area

In the spill area, the formaldehyde killed the plants and most of the terrestrial invertebrates, such as earthworms and pill bugs. After one year, plants such as clover, sow thistle, and dandelions were migrating into the spill area. No toxic effects of the formaldehyde were noted on aquatic life in the creek.

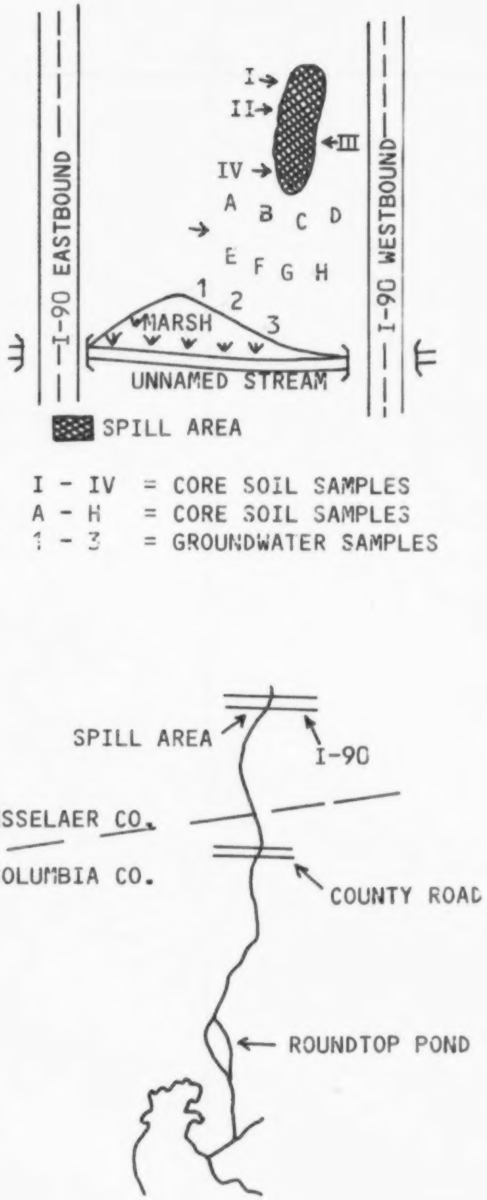
TABLE 27. WEATHER CONDITIONS, RENSSELAER, NEW YORK (RUFFNER AND BLAIR, 1978)

Month	Average Temperature °C	(°F)	Average Precipitation cm	(inches)	Average Wind Speed kmph	(mph)
January	-5.1	(22.7)	6.2	(2.47)	15.6	(9.8) WNW
February	-4.6	(23.7)	5.5	(2.20	16.4	(10.3) WNW
March	0.5	(33.0)	6.9	(2.72)	16.8	(10.5) WNW
April	7.8	(46.2)	7.0	(2.77)	16.6	(10.4) WNW
May	13.8	(57.9)	8.8	(3.47)	14.5	(9.1) S
June	19.6	(67.3)	8.2	(3.25)	12.9	(8.1) S
July	22.2	(72.1)	8.8	(3.49)	11.6	(7.3) S
August	21.1	(70.0)	7.7	(3.07)	11.0	(6.9) S
September	16.4	(61.6)	9.0	(3.58)	11.6	(7.3) S
October	10.4	(50.8)	7.0	(2.77)	12.6	(7.9) S
November	3.9	(39.1)	6.8	(2.70)	14.2	(8.9) S
December	-3.0	(26.5)	6.5	(2.59)	14.5	(9.1) S
Yearly Average	8.6	(47.6)	89.1	(35.08)	14.0	(8.8) S

TABLE 28. WEATHER CONDITIONS AFTER SPILL (RUFFNER AND BLAIR, 1978)

Date (1972)	Precipitation cm	Precipitation (inches)	Temperature Range °C	Temperature Range (°F)
June 6	.78	(0.31)	12.7-22.7	(55-73)
7	trace	trace	8.8-21.6	(48-71)
8	1.0	(0.41)	6.1-18.3	(43.65)
9	.9	(0.37)	13.8-25.0	(57-77)
10	.03	(0.01)	7.7-14.4	(46-58)
11	0.0	(0.0)	2.7-17.2	(37-63)
12	0.0	(0.0)	3.3-19.4	(38-67)
13	0.0	(0.0)	13.3-24.4	(56-76)
14	0.0	(0.0)	16.1-27.2	(61-81)
15	.2	(0.10)	17.2-28.3	(63-83)
16	1.7	(0.69)	17.2-24.4	(63-76)
17	0.0	(0.0)	13.3-24.4	(56-76)
18	0.0	(0.0)	13.3-25.0	(56-77)
19	2.0	(0.82)	16.1-21.6	(61-71)
June totals	17.0	(6.84)		
July totals	7.9	(3.10)		

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
DROPPED HEAD BEGIN SECTIONS HERE
BEGIN LAST LINE OF TEXT


I
II
III
IV
A B C D
E F G H
1 2 3
MARSH
I-90 EASTBOUND
I-90 WESTBOUND
UNNAMED STREAM
SPILL AREA
I - IV = CORE SOIL SAMPLES
A - H = CORE SOIL SAMPLES
1 - 3 = GROUNDWATER SAMPLES
SPILL AREA
I-90
RENSSELAER CO.
COLUMBIA CO.
COUNTY ROAD
ROUNDTOP POND

1 INCH = 0.84 KM

Figure 14. Spill area and sampling stations (Roush *et al.*, 1974).

PAGE NUMBER
EPA 287 (Cin)
(6-78)

TABLE 29. FORMALDEHYDE LEVELS IN SOIL SAMPLES IN PPM (ROUSH et al., 1974)

Station	Sample Depth cm	(in)	Date of Sample June 7, 1972	June 29, 1972	June 4, 1973
I.	detritus		ND*	11,960	ND*
	0-15	(0-6) core	23,000	705 (97%)**	138 (99.4)
	15-30	(6-12) core	34,000	550 (98.4%)	ND
II.	detritus		76,000	5,130 (93.2%)	ND
	0-15	(0-6) core	29,000	165 (99.4%)	99.2 (99.8)
	15-30	(6-12) core	ND	2,640	ND
III.	detritus		28,000	22,900 (18.2%)	ND
	0-5	(0-6) core	ND	700 (88.3%)	179 (97.0)
	15-30	(6-12) core	ND	240	ND
IV.	detritus		46,000	5,640 (87.7%)	0 (100)
	0-15	(0-6) core	8,000	1,470 (81.6%)	80 (99.0)
	15-30	(6-12) core	54,000	2,600 (95.2%)	ND

TABLE 30. FORMALDEHYDE LEVELS IN MARSH SOIL AND WATER SAMPLES IN PPM (ROUSH *et al*., 1974)

Station		Date of Sample		
		June 7, 1972	June 24, 1972	June 7, 1973
Marsh (A-H)	Mean	15	49	190
	Range	12-17	200-180	90-328
Ground Water 1-3		0-4	0.5-0.5	0.89

TOLUENE SPILL, WALLSBURG, UTAH

Background of Spill

A Hatch Company driver lost control of his truck at the intersection of highway 189 at Wallsburg Junction on June 17, 1977. The truck overturned blocking the road and spilling its contents of toluene. Details of the spill are listed in Table 31. A contour map of the spill area is shown in Figure 15.

Climate of Spill Area

The weather conditions of the Wallsburg, Utah area are presented in Table 32. June, the month of the spill, is typically one of the dryest months of the year. Winds average 14.5 kmph (8.7 mph) for the south-southeast.

Geology of Spill Area

The soil in the spill area is made up of 70% cubbly sandy/clay loam, 20% rock outcrop and 10% other soils. Rock in the area is primarily sand stone. The average depth of the soil in the area is 51 cm before bedrock (Woodward, 1925).

Response to Spill

The spill area was sanded by the County Highway Department. The contaminated sand was then removed from the area (Hinshaw, personal communication, 1979). The toluene that was not released was pumped into other Hatch Company tankers. Highway 189 was closed for over 8 hours during the clean-up.

Environmental Levels of Spilled Material

No measurements were conducted by on-site spill personnel.

Biological Damage to Area

No biological damage was reported to area.

ARSENIC TRIOXIDE SPILL, ELKHORN, WISCONSIN

Background of Spill

A Milwaukee Railroad train derailed on July 30, 1977, due to an improperly aligned switch. Two flat cars, with two trailers on each flat car were involved in the derailment. The trailers contained a total of 360 drums of arsenic trioxide (200 kg each). Forty-three of these drums broke open releasing their powdered contents. The spill site was located near a cornfield in Elkhorn, Wisconsin. Residential areas were approximately .4 km (1/4 mile) away. Details of the spill are listed in Table 33. A contour map of the area is presented in Figure 16.

Climate of Spill Area

The weather conditions for the Elkhorn, Wisconsin area are presented in Table 34. July through September are the months with the heaviest precipitation. The winds during summer months, when the spill occurred, are moderate

TABLE 31. BACKGROUND OF TOLUENE SPILL, WALLSBURG, UTAH

Chemical Spilled	Toluene
Class of Material	Flammable Liquid
Amount Spilled	14,146 liters
How Occurred	Accident (Overturned truck)
Date	June 17, 1977
Time	1:25 p.m.
Location	Wallsburg, Utah Wallsburg Junction and U189
On-site Spill Coordinator	Summit County Sheriff

Reproduced from best available copy.

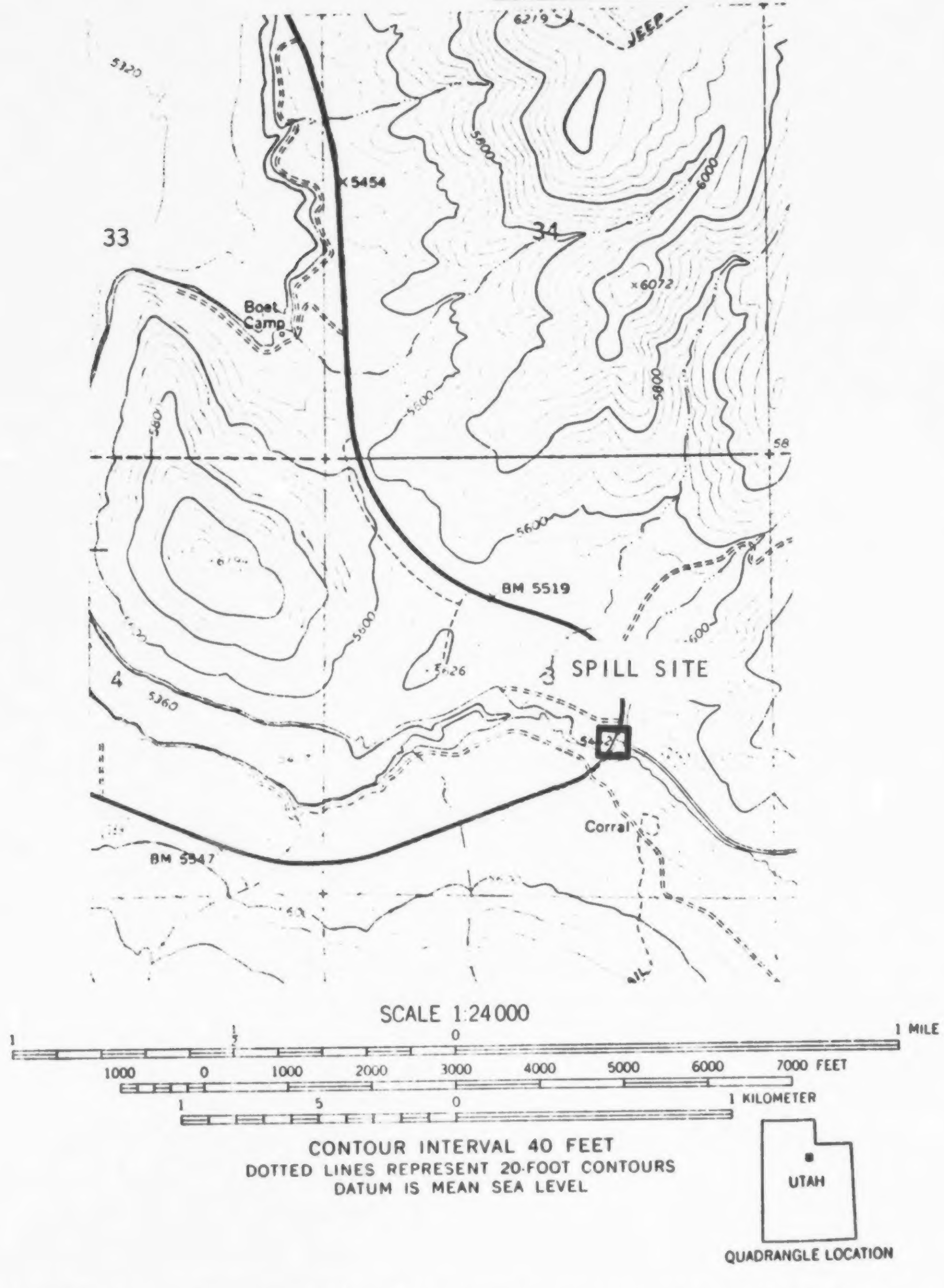

6219
JEEP
5320
5800
6000
X 5454
33
34
X 6072
Boat Camp
5800
5600
5800
58
5600
BM 5519
5800
5600
SPILL SITE
5426
3
4
5360
Corral
BM 5547
SCALE 1:24 000
1
½
0
1 MILE
1000
0
1000
2000
3000
4000
5000
6000
7000 FEET
1
.5
0
1 KILOMETER
CONTOUR INTERVAL 40 FEET
DOTTED LINES REPRESENT 20-FOOT CONTOURS
DATUM IS MEAN SEA LEVEL
UTAH
QUADRANGLE LOCATION

Figure 15. Topography of toluene spill area, Wallsburg Utah (U.S. Geological Survey, 1966)

TABLE 32. WEATHER CONDITIONS, WALLSBURG, UTAH (RUFFNER AND BLAIR, 1978)

Month	Average Temperature °C	(°F)	Average Precipitation cm	(inches)	Average Wind Speed kmph	(mph)
January	-6.5	(20.3)	4.6	(1.83)	12.3	(7.7) SSE
February	-3.7	(25.3)	4.1	(1.64)	13.1	(8.2) SE
March	1.1	(34.0)	3.5	(1.40)	14.7	(9.2) SSE
April	6.8	(44.3)	2.9	(1.16)	15.2	(9.5) SE
May	11.1	(52.1)	2.7	(1.07)	14.8	(9.3) SE
June	15.0	(59.0)	2.3	(0.93)	14.8	(9.3) SSE
July	19.3	(66.9)	2.1	(0.83)	15.0	(9.4) SSE
August	18.6	(65.5)	2.7	(1.08)	15.2	(9.5) SSE
September	14.2	(57.6)	1.8	(0.72)	14.4	(9.0) SE
October	8.8	(47.9)	3.3	(1.31)	13.6	(8.5) SE
November	1.5	(34.7)	3.6	(1.44)	12.4	(7.8) SSE
December	-3.5	(25.7)	5.0	(1.98)	12.0	(7.5) SSE
Yearly Average	6.8	(44.4)	39.0	(15.38)	13.9	(8.7) SSE

TABLE 33. BACKGROUND OF ARSENIC TRIOXIDE SPILL, ELKHORN, WISCONSIN

Chemical Spilled	Arsenic Trioxide
Class of Material	Poison B
Amount Spilled	8,581.9 kg
How Occurred	Derailment
Date	July 30, 1977
Time	8:05 a.m.
Location	Elkhorn, Wisconsin
On-site Spill Coordinator	Mr. F. Haseley Wisconsin Department of Natural Resources

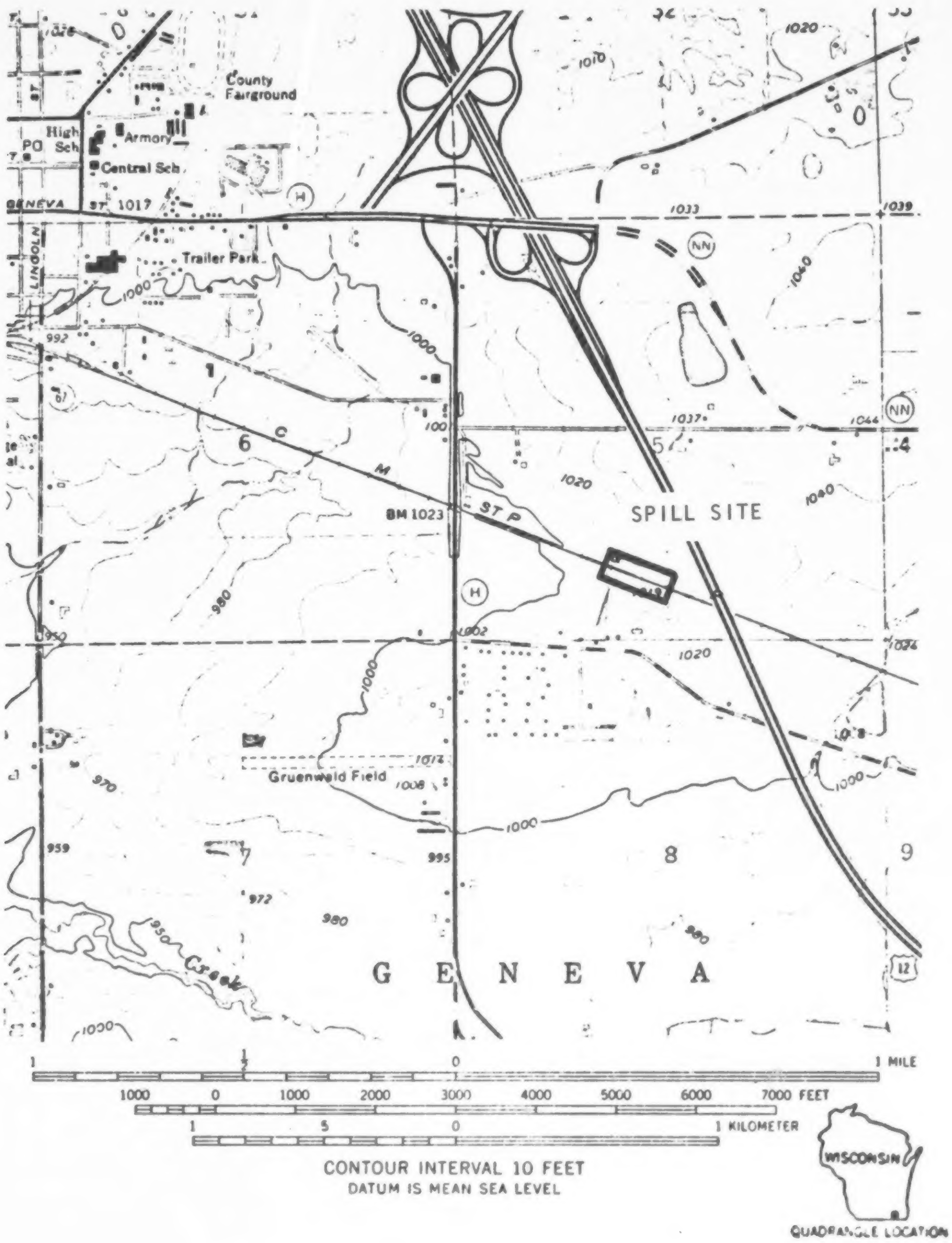

County Fairground
High Sch
PO
Armory
Central Sch
GENEVA ST. 1017
LINCOLN
Trailer Park
1000
992
1010
1020
1033
1039
NN
1040
1037
1044
H
6
5
4
C M ST P
BM 1023
1020
SPILL SITE
1040
980
1002
1020
1026
1000
Gruenwald Field
1012
1008
970
959
7
972
980
995
8
9
980
950
Creek
G E N E V A
12
1000
1 MILE
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 KILOMETER
CONTOUR INTERVAL 10 FEET
DATUM IS MEAN SEA LEVEL
WISCONSIN
QUADRANGLE LOCATION

Figure 16. Topography of arsenic trioxide spill site, Elkhorn Wisconsin, (U.S. Department of Geological Survey, 1971).

TABLE 34. WEATHER CONDITIONS, ELKHORN, WISCONSIN
(RUFFNER AND BLAIR, 1978)

Month	Average Temperature		Average Precipitation		Average Wind Speed		
	°C	(°F)	cm	(inches)	kmph	(mph)	
January	-9.3	(15.2)	2.5	(0.99)	14.5	(9.1)	S
February	-7.9	(17.7)	2.1	(0.85)	14.7	(9.2)	NW
March	-2.0	(28.3)	4.2	(1.67)	15.6	(9.8)	NW
April	6.7	(44.2)	6.9	(2.73)	18.2	(11.4)	NW
May	13.3	(56.9)	10.0	(3.95)	16.9	(10.6)	S
June	19.0	(66.3)	12.9	(5.11)	14.0	(8.8)	S
July	21.6	(71.0)	8.5	(3.36)	12.6	(7.9)	S
August	20.3	(68.6)	8.7	(3.46)	12.3	(7.7)	S
September	15.5	(60.0)	8.7	(3.46)	13.7	(8.6)	S
October	9.3	(48.9)	5.7	(2.26)	15.8	(9.9)	S
November	0.4	(32.8)	4.6	(1.83)	16.8	(10.5)	S
December	-6.5	(20.2)	2.54	(1.00)	14.7	(9.2)	S
Yearly Average	6.7	(44.2)	77.9	(30.67)	15.0	(9.4)	S

from the south. The weather conditions immediately after the spill are presented in Table 35. Wind direction on the day of the spill was from the west dispersing the compound into a cornfield. The month of August, had 12 cm (4.69 inches) of rain or 3.1 cm (1.23 inches) over the normal amount.

Geology of Spill Area

The soil at the spill site is a Pella silt loam. The Pella series are usually deep, poorly drained soils. The soil is a silt loam from 0-30 cm (0-12 inches), a silty clay loam from 30-107 cm (42-60 inches) and a silt loam from 107-152 cm (42-60 inches). The estimated depth to the water table is 0-30 cm (0-1 feet). The pH ranged from 6.6-8.4 and the permeability is 1.6-6.6 cm per hour (USDA, 1971).

Response to Spill

The derailment had damaged 43 of the 360 drums containing arsenic trioxide releasing at most 8,582 kg (18,920 pounds) of the compound. Some of the powder was blown into cornfields adjacent to the tracks. Railroad personnel contacted O & H Materials. They started clean-up of the area on July 31 and finished on August 4. Full protective clothing, including self-contained breathing apparatus, was used during the clean-up. Care was taken to keep dust emissions to a minimum, however, Mr. Ehart (personal communication, 1979) noted that some release in the wind did occur during removal of the chemical.

The broken arsenic trioxide drums were piled on the north side of the tracks and covered with soil. On 1 August, 150 special barrels were shipped to the site to hold the contaminated material. The contaminated soil and arsenic debris were removed by wetting down the area, picking them up with a front end loader and placing the material in the barrels. The contaminated materials were then taken to an atomic waste disposal site in Sheffield, Illinois.

Environmental Levels of Spilled Material

Water samples were collected from three wells and two swimming pools in the Green Acres subdivision, .4 km (1/4 miles) south-west of the spill site. Samples were also taken from two farm pools .8 km (1/2 miles) from the site. No arsenic was detected in the water samples. The State Laboratory of Hygiene in Madison, Wisconsin, performed the analyses. Their detection limit for arsenic was 10 ppb.

Soil samples were also collected in the area. At the spill site, before clean-up, 7,600 ppm of arsenic were present in the soil. However, .8 km (1/2 miles) away, the levels were only 0.8 ppm (Lichtenwalner, personal communcation 1977).

Biological Damage to Area

The cornfield near the spill site was not allowed to be harvested. The arsenic was not toxic to the plants. However, a bird was found dead from arsenic poisoning 6 months after the spill, so some unnoticed biological damage could have occurred (Ehart, personal communication, 1979).

TABLE 35. WEATHER CONDITIONS AFTER THE SPILL (RUFFNER AND BLAIR, 1978)

Date	Precipitation cm	(inches)	Temperature Range °C	(°F)
July 30	0.0	(0.0)	14.4-32.2	(58-90)
July 31	0.02	(0.01)	16.1-31.1	(61-88)
August 1	0.0	(0.0)	11.1-28.3	(52-83)
August 2	0.2	(0.08)	13.8-26.6	(57-80)
August 3	Trace		13.8-28.3	(57-83)
August 4	1.34	(0.53)	16.1-27.2	(61-81)
August 5	0.9	(0.39)	17.7-26.6	(64-80)
August 6	0.02	(0.01)	15.0-26.1	(59-79)
August 7	Trace		19.4-28.8	(67-84)
August 8	2.5	(0.99)	17.2-28.8	(63-84)
August 9	0.4	(0.17)	17.2-26.6	(63-80)
August 10	0.0	(0.0)	17.2-28.3	(63-83)
August 11	0.12	(0.05)	10.0-26.6	(50-80)
August 12	0.0	(0.0)	14.4-26.6	(58-80)
August Total	11.9	(4.69)		
September Total	7.5	(2.96)		

CONCLUSIONS ON LAND RESTORATION METHODS

The two acrylonitrile spills were excellent examples of innovative treatments of spill damaged land. The spill response team in Leon, Kentucky, used aeration ponds to remove the chemical from the soil. In the Dayton, Ohio, spill, where the acrylonitrile was at or near the surface, a chemical reaction was conducted to degrade the compound. Both of these treatments were successful in removing the acrylonitrile and were less costly, in dollars and in environmental damage, than removing the contaminated soil.

The phenol spill in Slabtown, Maryland, also employed an interesting treatment method. Activated carbon was used to remove the chemical from the water leaching from the contaminated soil.

Near Kingston, Tennessee, the PCB spill could not be treated by chemical or biological methods. Therefore, massive amounts of contaminated soil were removed from the spill site. The data collected shortly after the spill and several years later indicated that the PCB in the soil had not been degraded.

The previously discussed spills had all endangered surface or subsurface waters. When the water in a spill area is not threatened, less costly treatment methods are often used. For example the toluene spill in Wallsburg, Utah, did not threaten waterways. The contaminated area from this spill was sanded and then the contaminated material was removed. The nitric acid spill in Estill, South Carolina, was neutralized with lime and contaminated soil was removed to a land fill. In Duffee, Mississippi, the spill of sodium hydroxide was initially treated by burying the contaminated soil. However, when residents complained about fumes, the contaminated soil was neutralized with alum. The formaldehyde spill in Rensselear County, New York, received no treatment. The formaldehyde was removed from the soil by natural mechanisms within one year after the spill.

The spill of arsenic trioxide, near Elkhorn, Wisconsin, was an example of the problems of contamination when a powder is spilled. Winds were responsible for spreading the material and special methods were required to remove the contaminated material from the site.

The spills discussed in greater detail in this section do not represent a typical cross section of the treatment methods used. Mercer, et al.(1978) reviewed the treatments applied to 78 hazardous material spills which were reported to the Oil and Hazardous Materials Spills Branch of the EPA at Edison, New Jersey. These spills occurred from December 1975 to May 1976. A tabulation of the treatment applied to the spills is presented in Table 36. About 11% of the spills were chemically treated. These were acid or base spills. The acids were neutralized with lime, limestone or soda ash. The only base spill included in the sample, was neutralized with hydrochloric acid. In 60 percent of the spills either no treatment was applied or the treatment method used consisted only of a water wash. Therefore, in the overwhelming majority of the spills examined by Mercer et al. (1978), a quick inexpensive solution was the method of treatment of the spill.

TABLE 36. TREATMENT METHODS FOR HAZARDOUS MATERIAL SPILLS (MERCER *et al*., 1978)

Method Used	No. of Incidents	Percent of Total
None	28	36
Water Wash	19	24
Chemical Treatment	9	11
Recovery	6	8
Landfill	2	3
Biological Treatment	1	1
Nothing Reported	13	17
Total	78	100

EPA Form 2350-4 (4-80)
(PREVIOUSLY EPA FORM 287)
TYPING GUIDE SHEET

SECTION 5

FATE OF HAZARDOUS MATERIAL SPILLS ON LAND AND POTENTIAL RESTORATION METHODS

FATE OF HAZARDOUS MATERIALS SPILLED IN THE ENVIRONMENT

Once a hazardous material is spilled on land, it can undergo a variety of processes including:

- adsorption - desorption in the soil
- leaching into surface water
- leaching into ground water
- chemical degradation
- microbial degradation
- uptake by plants and animals leading to toxic effects, bioconcentration, bioaccumulation, and/or degradation

The goal of the spill response team is to optimize the removal of the chemical from the environment and minimize the contamination of water supplies and toxic effects to humans, animals, and plants. Thus, the initial response to a spill is the removal of as much of the hazardous material from the environment as possible. This task can be accomplished by a variety of physical-chemical methods depending on the properties of the material spilled. However, restoration of the land requires additional efforts which can be very costly.

RESTORATION OF SPILL DAMAGED LANDS: PREVIOUSLY USED TECHNIQUES

Three techniques have been applied in the past to aid in the restoration of spill damaged land:

- remove damaged soil and replace with clean soil
- wash chemical out of soil, collect and adsorb on activated carbon
- chemical neutralization

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 287)

TYPING GUIDE SHEET

Remove Damaged Soil

An area contaminated by a spilled chemical can be restored by removal of the top layer of soil and replacing it with clean soil. This restoration method utilizes only conventional farm equipment to remove the damaged soil and appropriate clothing to protect workers from adverse effects from the spilled chemical. The damaged soil is hauled to a secure landfill. The spill area is then backfilled in with top soil and revegetated.

Removal of damaged soil is an expensive undertaking especially if the spill is large and significant penetration of the soil has occurred. Toxic fumes released in the digging operation can create a serious health problem for workers and the nearby environment. Disposal of the contaminated soil is also a major problem since it must be hauled to a secure landfill.

Thus, removal of damaged soil is only a viable alternative if large water supplies, a large number of people, wildlife or highly valuable land are threatened.

Collection and Carbon Adsorption

Collection of leached water containing the spilled chemical followed by carbon adsorption treatment to remove the chemical from the water has been proven to be a viable spill clean-up method. This technique works best if the runoff water from the spill area can be easily channelled into one or two carbon adsorption units by using trenches or the land contour. If the spilled material is efficiently adsorbed by the carbon, the effluent water can be returned to the environment. The spent carbon can be disposed of in a secure landfill or by burning, depending on the nature of the chemical. The main disadvantages of carbon adsorption treatment are:

- continuous monitoring of the effluent is required in order to assure that the carbon filtration system is operating efficiently
- the contour and consistency of the land may not be suitable for collection of runoff or drainage water without considerable excavation
- long term use of carbon adsorption is expensive

Chemical Neutralization

Many hazardous chemicals can be rendered harmless by reaction with other chemicals in a relatively simple reaction, e.g., neutralization of sulfuric acid with base. However, unless the spilled material is near the surface and relatively localized, neutralization procedures can cause more damage to the land. The increased damage can be due to excess of the neutralization chemical, heat of reaction or formation of toxic by-products. Thus, chemical neutralization must be considered on a case-by-case basis since the area covered by the spill, the type of land and weather conditions will determine if neutralization will prevent or cause further damage.

Restoration of Spill-Damaged Land - New Potentially Useful Techniques

The literature was surveyed for potentially useful techniques which could be applied to the restoration of spill damaged land. Techniques which were identified can be divided into four categories:

- microbial degradation
- selective absorption by harvestable plants
- revegetating the area
- optimization of photochemical degradation

Microbial Degradation

In conjunction with the widespread use of pesticides on land, many researchers have investigated the biodegradation of pesticides by microorganisms in soil and water. A great number of microorganisms are capable of degrading pesticides. A list of some of these organisms and the pesticides they degrade is presented in Table 37. In many instances,a pesticide that is not degraded by an organism in a pure culture can be degraded by the organism when a supplementary source of energy is present. This phenomenon is known as co-metabolism and is an important mechanism of pesticide degradation in the soil (Haque and Freed, 1975).

Almost all degradation transformations are accounted for by oxidative, reductive, hydrolytic, and/or conjugative reactions; all of which are fundamental to all biological systems. These types of transformations and the pesticides in which they occur and the end products of pesticide transformation are presented in Table 38.

According to Haque and Freed (1975), there are a number of factors influencing the rates of degradation. Those factors that reduce the rate are:

- sorption, unless degradation is catalyzed at the sorptive soil surface
- substitution in the ring meta to the hydroxyl of chlorophenols rather than substitution in the ortho or para position

The factors that increase the rate of degradation are:

- presence of ester linkages separating highly polar groups
- alkaline soil
- presence of clay and metallic cations
- increased soil moisture
- increased soil temperature

TABLE 37. MICROORGANISMS REPORTED TO DEGRADE PESTICIDES (HAQUE AND FREED, 1975)

Achromobacter	2,4-D, DDT, 2,4,5-T
Aerobacter	DDT, endrin, methoxychlor
Agrobacterium	Dalapon, DDT, picloram
Alcaligenes	Dalapon, maleic hydrazine
Arthrobacter	2,4-D, dalapon, diazinon, picloram
Aspergillus	2,4-D, endrin picloram, trichlorfon
Bacillus	Dalapon, DDT, dieldrin, heptachlor, methyl parathion, parathion, picloram
Botrytis	Picloram
Cephaloascus	PCP
Clostridium	DDT, lindane, paraquat
Corynebacterium	2,4-D, dalapon, DDT
Erwinia	DDT
Escherichia	DDT, lindane
Flavobacterium	2,4-D, dalapon, maleic hydrazine, picloram
Fusarium	Aldrin, atrazine, DDT, heptachlor, trichlorfon
Helminthosporium	Picloram
Kurthia	DDT
Micrococcus	Dalapon
Micromonospora	Heptachlor
Mucor	DDT
Mycoplana	2,4-D, 2,4,5-T
Nocardia	Allyl alcohol, 2,4-D, dalapon, DDT, heptachlor, picloram
Penicillium	Aldrin, dalapon, heptachlor, picloram, triclorfon
Proteus	DDT
Psuedomonas	Allyl alcohol, 2,4-D, dalapon, DDT, diazinon, dieldrin, endrin, malathion
Rhizopus	Heptachlor
Saccharomyces	Captan, picloram
Serratia	DDT
Sporocytophaga	2,4-D

(continued)

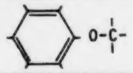
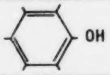
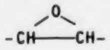
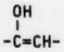
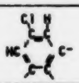
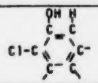
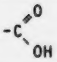
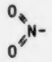
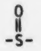
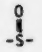
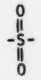
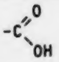
EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 257)
TYPING GUIDE SHEET

TABLE 37. (CONTINUED)

Streptococcus	DDT, heptachlor
Streptomyces	Dalapon, diazinon
Tramates	PCP
Trichoderma	Aldrin, allyl alcohol, DDT, diazinon, dieldrin, heptachlor, malathion, PCB, picloram

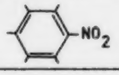
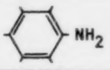
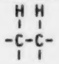
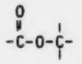
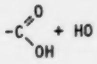
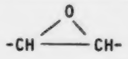
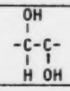
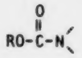
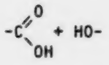
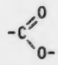
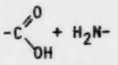
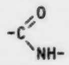
BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD; BEGIN SECTIONS HERE
6 1/2"
9 1/8"
BEGIN LAST LINE OF TEXT
3/8"
PAGE NUMBER
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 267)
TYPING GUIDE SHEET

TABLE 38. TYPES OF PESTICIDE TRANSFORMATIONS IN SOIL AND/OR PLANTS (HAQUE AND FREED, 1975)

Type of Reaction	Initial Group	Reaction Product	Pesticide (or their Metabolites) Involved
Oxidative	$-\overset{\vert}{\underset{\vert}{C}}-H$	$-\overset{\vert}{\underset{\vert}{C}}-OH$	Carbaryl, DDT, Dieldrin
"			2,4-D, Dicamba, Methoxychlor 2,4,5-T
"	-CH=CH-		Aldrin, Carbaryl, 2,4-D, Heptachlor, Picloram
"	-CH=CH- (aromatic)	 $-\overset{OH}{\overset{\vert}{C}}=CH-$	Carbaryl, 2,4-D, Dicamba, Diuron
"			2,4-D
"	$-CCl_3$		DDT
"	$-\overset{\vert}{\underset{\vert}{C}}-Cl$	$-\overset{\vert}{\underset{\vert}{C}}-OH$	Dalapon, Heptachlor
"	$\overset{\vert}{\underset{\vert}{N}}-$		Diuron
"	$-\overset{\vert}{\underset{\vert}{P}}=S$	$-\overset{\vert}{\underset{\vert}{P}}-O$	Disulfoton, Malathion, Parathion
"	-S-	 $-\overset{O}{\overset{\Vert}{S}}-$	Disulfoton
"	 $-\overset{O}{\overset{\Vert}{S}}-$	 $-\overset{O}{\overset{\Vert}{\underset{O}{\underset{\Vert}{S}}}}-$	Disulfoton, Ednosulfon
Reductive		-H	2,4-D, DDT

(continued)

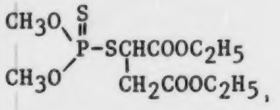
TABLE 38. (CONTINUED)

Type of Reaction	Initial Group	Reaction Product	Pesticide (or their Metabolites) involved
Reductive			Parathion
"	$>C=C<$	 $-\overset{H}{\underset{|}{\overset{|}{C}}}-\overset{H}{\underset{|}{\overset{|}{C}}}-$	DDT
"	$-\overset{|}{\underset{|}{C}}Cl$	$-\overset{|}{\underset{|}{C}}H$	DDT, Heptachlor, Lindane Methoxychlor
Hydrolytic (addition of water including oxidative hydrolysis)	 $-\overset{O}{\overset{\|}{C}}-O-\overset{|}{\underset{|}{C}}-$	 $-C(=O)OH + HO$	2,4-D esters, Malathion
"		 $-\overset{OH}{\overset{|}{C}}-\underset{\underset{H\;\;OH}{|\;\;\;|}}{C-C}-$	Dieldrin
"	 $RO-\overset{O}{\overset{\|}{C}}-N<$	$ROH + CO_2 + HN<$	Carbaryl, Mexacarbate
Conjugative (elimination of water, HX (x = halo) and H)	 $-C(=O)OH + HO-$	 $-C(=O)O-$	2,4-D, Picloram, Dicamba
"	 $-C(=O)OH + H_2N-$	 $-C(=O)NH-$	2,4-D, Diuron, Picloram
"	$-OH$	$-OCH_3$	2,4-D

BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD; BEGIN SECTIONS HERE
BEGIN LAST LINE OF TEXT
3/8"
PAGE NUMBER
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 287)
U.S. GOVERNMENT PRINTING OFFICE
TYPING GUIDE SHEET

The above are very simple generalizations. In reality, there is interaction between all factors and the situation is very complex. For example, compounds that are in a highly oxidized state may resist further oxidation under aerobic soil conditions. However, the same compound may be degraded by reduction under anaerobic conditions (Haque and Freed, 1975).

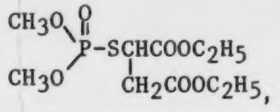
Walker and Stojanovic (1973) studied the degradation of malathion,



an organic phosphate pesticide, on clay, loam and sandy loam under both sterile and non-sterile conditions. As shown in Table 39, the malathion had been almost totally degraded in the non-sterile soil within 10 days. The degradation that occurred in the sterile soil was attributed to chemical degradation, rather than microbial. Microbial degradation was defined as the difference between the total degradation and the chemical degradation. Chemical degradation appeared to be due to alkaline hydrolysis and adsorption by the soil particles. Susceptibility to hydrolysis increased with increasing alkalinity.

Other researchers have also studied malathion. Matsumura and Boush (1968) found that the fungus *Trichoderma viride* and a bacterium, *Pseudomonas* sp., degraded malathion. *T. viride* also degraded diazinon, dichlorovos and parathion (Matsumura and Boush, 1968).

Although malathion is rapidly degraded by soil microorganisms, malaoxon,



an oxo-analog formed either photochemically on plants or by soil microorganisms,

TABLE 39. PERCENTAGE OF CHEMICAL AND MICROBIAL DEGRADATION OF MALATHION IN SOIL AFTER 10 DAYS (WALKER AND STOJANOVIC, 1973)

		% Total Degradation Due to	
Sample	Total Degradation	Chemical Mechanisms	Microbial Mechanisms
Clay	100	23	77
Loam	100	9	91
Sandy Loam	99	5	95

is not degraded by microorganisms and is highly toxic (Paschal and Neville, 1976). Paschal and Neville (1976) applied both malaoxon and malathion to sterile and non-sterile soil. The rates of disappearance of malaoxon from the soil samples at pH of 6.2, 7.2, and 8.2 are shown in Figure 17. The data indicated that the disappearance of malaoxon is more dependent on the pH than on the presence of microorganisms in the soil. Thus, malaoxon disappearance is due to chemical hydrolysis which increases with pH. Paschal and Neville (1976) also reported that malaoxon reduced the bacterial population by 50% and the fungal population by 95% in the non-sterile soil.

The disappearance of malathion from the sterile and non-sterile soils at a pH of 7.2 is shown in Figure 18. Malathion was not degraded in the sterile soil. After application of malathion, the numbers of bacteria and fungi were the same as before the application regardless of soil pH. Paschal and Neville (1976) concluded malathion was degraded by microorganisms, while the malaoxon was degraded by chemical mechanisms.

Many researchers have studied the degradation and bioconcentration of dalapon (CH_3CCl_2COOH). After treatment of plant roots with dalapon, it has been found that the dalapon accumulates, but does not degrade in corn plants (Blanchard *et al*., 1960; Foy, 1961), soybean plants (Blanchard *et al*., 1960), cotton plants (Smith and Dyer, 1961; Foy, 1961) and wheat (Foy, 1961). In none of the above cases was pyruvic acid, one of the breakdown products of dalapon, found in plant tissues. However, unchanged dalapon was present in plant tissues in all cases.

Many microorganisms are capable of degrading dalapon after a lag period during which the bacteria acclimate to the dalapon as an energy source. Kearney *et al*. (1964) found that species of *Pseudomonas*, *Agrobacterium*, *Bacillus*, *Alcaligenes*, *Arthrobacter* and *Nocardia* were able to degrade dalapon in pure cultures.

Corbin (1965) studied the effect of dalapon on soil invertebrates. He reported dalapon applied at 22.4 kg/ha (40 lb/A) or 11.2 kg/Ha (20 lb/A) did not affect wire worm populations. A dosage of 11.2 kg/ha (20 lb/A) resulted in slightly increased numbers of millipedes and springtails the first year and an increase in numbers of mites in the first and second years.

Day *et al*. (1963) reported the rate of degradation of dalapon was not related to soil texture, cation-exchange capacity, total organic matter, or source, but was related to differences in populations of soil organisms.

Kuwatsuka and Niki (1976) studied the degradation of PCP, 2,4-D, paraquat and diquat.

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD: BEGIN SECTIONS HERE

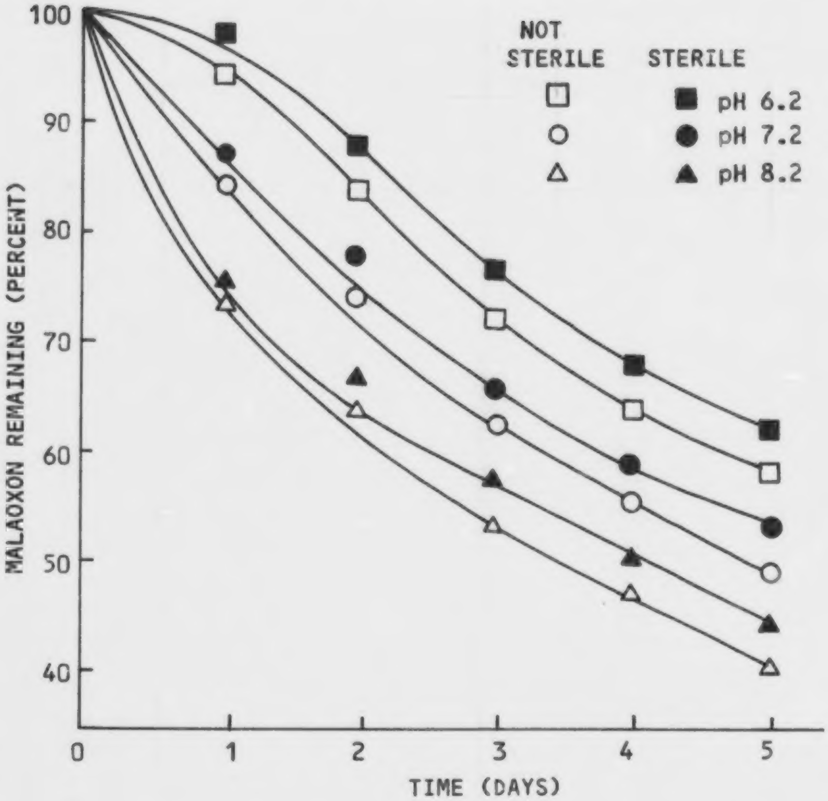


Figure 17. Disappearance of malaoxon in sterile and non-sterile soil samples at pH 6.2, 7.2 and 8.2 (Paschal and Neville, 1976).

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD BEGIN SECTIONS HERE

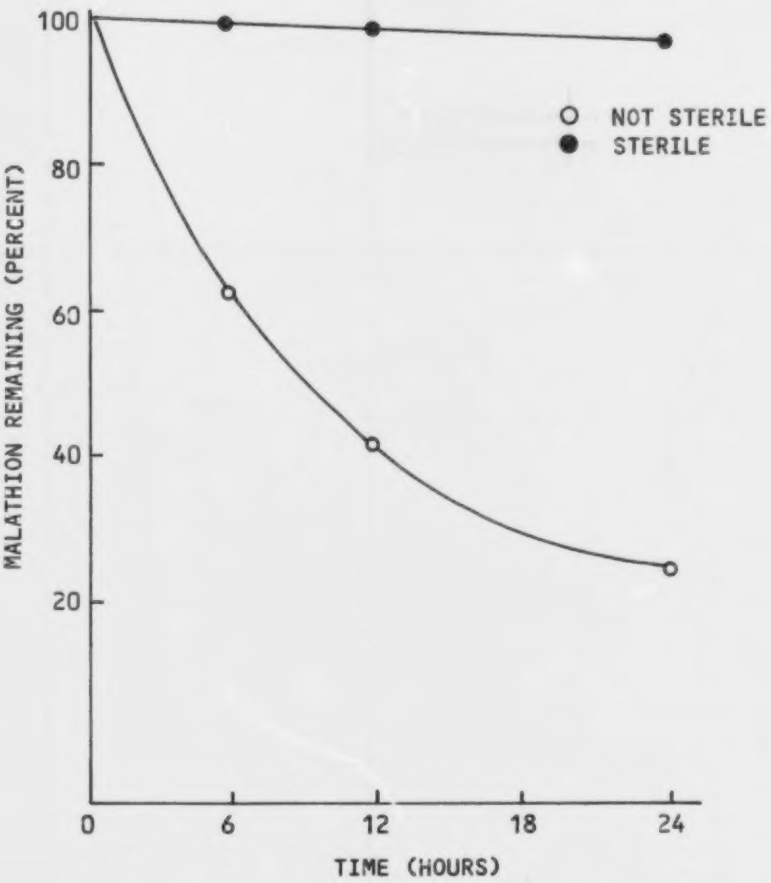
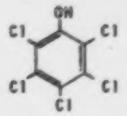


Figure 18. Disappearance of malathion in sterile and non-sterile soil samples at pH 7.2 (Paschal and Neville, 1976).

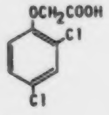
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS

PAGE NUMBER
EPA-287 (Cin.)

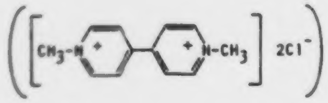
PCP



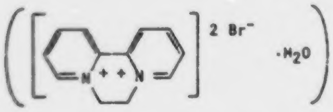
2,4-D



paraquat



diquat



on flooded and non-flooded soil conditions. They found the degradation of these chemicals to be affected by many factors:

- organic matter content
- kind of clay minerals
- clay content
- pH
- redox potential
- moisture content
- structure and texture of soil

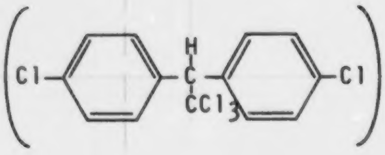
The different pesticides were affected differently by each of these properties.

PCP degradation was approximately proportional to organic matter content and PCP degraded faster at higher temperatures under flooded conditions. Under non-flooded conditions, differences in soil temperatures did not make much difference in degradation rates (Kuwatsuka and Niki, 1976). Although PCP was degraded rapidly under flooded conditions, 2,4-D was degraded more rapidly under non-flooded conditions (Kuwatsuka and Niki, 1976). Kuwatsuka and Niki (1976) also found that repeated application of PCP resulted in accelerated degradation which took place by both microbial mechanisms and non-microbial mechanisms. In the microbial degradation of PCP, chlorine is liberated and metabolic products are partly incorporated into microbes and finally metabolized to carbon dioxide (Kuwatsuka and Niki, 1976).

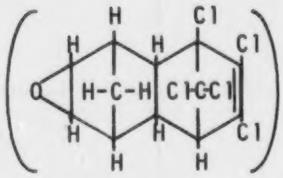
Kuwatsuka and Niki (1976) also studied the degradation of dipyridynium herbicides, such as paraquat and diquat. They found that these pesticides were adsorbed onto soil particles and that degradation in the soil did not take place. However, paraquat was easily degraded by *Lypomyces starkei* in an aqueous culture medium.

Chen *et al*. (1977) investigated the adsorption of DDT, and dieldrin.

DDT



dieldrin



by potato plants under subtropical conditions. They applied DDT and dieldrin at a rate of 5 kg of active ingredient/ha to the soil in the fall and again in the spring. Immediately after the first application, sweet potatoes and white potatoes were planted. The persistence of the two chemicals was found to be similar. During the fall and winter, DDT declined by only 20%, dieldrin by 25%. However, the decline was accelerated during the spring and summer, despite the additional spring application of the chemicals. Soil residues of DDT were lower at the end of the summer than before the second application in the spring. The concentration of dieldrin at the end of the summer was identical to the concentration before treatment.

These insectcies were adsorbed by the potatoes either as the parent compounds or their metabolites (Chen et al., 1977), as shown in Table 40. The higher the concentration of insecticide in the soil, the higher the concentration in the plants.

From their studies,Chen et al. (1977) determined that the time required for 50% of the p,p'-DDT to disappear in the winter was 8 months; for dieldrin 7.5 months. They concluded that the rapidity with which the insecticides were degraded was due to the subtropical conditions.

Byast and Hance (1975) examined the capacity of 4 soil samples from Viet Nam to degrade 2,4,5-T. ^{14}C-carboxyl labelled 2,4,5-T butyl ester was applied to 2 samples to give a concentration of 1 ppm; the other two samples had a concentration of 15 ppm. The soils with 1 ppm evolved 64-69% of the $^{14}CO_2$ in 49 days while the soil with 15 ppm evolved 74-96% as $^{14}CO_2$ in 168 days. Although Byast and Hance (1975) tried to extract the 2,4,5-T remaining in the soil, they were able to extract only 4% of the quantity applied at 1 ppm and 1-16% of the 15 ppm application. Presumably, the inextractable 2,4,5-T had been incorporated into the soil organic matter.

Stojanovic et al. (1972) investigated the effects of twenty analytical grade pesticide standards, 20 pesticides formulated with liquid carriers and 7 mixtures of these formulations on a calcareous loam soil. The extent of biodegradation was determined from the amount of CO_2 evolved and the effects on microorganisms determined from plate counts. The pesticides applied were:

Atrazine
Bromacil
Dieldrin
Diuron
2,4,5-T
Trifluralin

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 387)
TYPING GUIDE SHEET

TABLE 40. INSECTICIDE ADSORPTION BY SWEET POTATOES AND WHITE POTATOES FROM TREATED SOIL (CHEN ET AL., 1977)

		Recovered from Crops, ppm			
		DDT			
Season	Crop	p.p'-DDT	p.p'-DDE	o.p'-DDT	Dieldrin
Fall 1974	Sweet potato[a]	0.15 ±0.05	0.02 ±0.01	0.06 ±0.03	0.07 ±0.02
	White potato[b]	0.26 ±0.11	0.03 ±0.01	0.09 ±0.07	0.33 ±0.10
Spring 1975	Sweet potato[c]	0.06 ±0.00	0.02 ±0.01	0.03 ±0.00	1.05 ±0.16

[a] Harvested on April 14, 1975.

[b] Harvested on March 4, 1975.

[c] Harvested on September 15, 1975.

Carbaryl
2,4-D
Dalapon
Paraquat
Dicamba
DNBP
DSMA
Malathion
DDT
PMA
Vernolate
Zineb
DBCP
Picloram

The amount of pesticide applied was 11,227 kg/ha (5 tons/acre) of active ingredients. Soil samples were incubated for 56 days. Of the analytical standards, those that were degraded were picloram (36% degraded), dieldrin and paraquat (13%) and vernolate (3%). Dieldrin historically thought to be highly residual in soil, was probably chemically decomposed into biodegradable products which were in turn degraded by microorganisms (Stojanovic et al., 1972).

The remaining pesticides inhibited the release of CO_2 from the soil samples, i.e., the soil samples released less CO_2 than the control sample which had no pesticide added. Half of the pesticides resulted in 10 to 30% reduction of CO_2 production. DNBP and 2,4-D showed the greatest inhibitory effect.

All of the analytical pesticides reduced the number of bacteria except bromacil and DBCP which increased the number of bacteria. Picloram and DNBP affected the bacterial count most severely. Streptomyces population were only slightly affected by the pesticides. Only diuron, dalapon, dicamba, picloram and DNBP reduced the number of viable Streptomyces. The soil samples treated with the remainder of the pesticides had increased Streptomyces populations over that observed in the control samples.

Fungi also survived the pesticides better than the bacteria. Vernolate, 2,4-D, dalapon, pichloram, zineb, bromacil, dicamba, 2,4,5-T, trifluralin and atrazine increased the numbers of fungi. However, DSMA, malathion, carbaryl, DDT, dieldrin, diuron, DBCP and paraquat reduced the numbers of fungi while PMA and DNBP killed off the entire fungal population (Stojanovic et al., 1972).

Of the pesticide formulations, about half were degraded, while the other half inhibited the release of CO_2 from the soil. According to Stojanovic et al. (1972), picloram and 2,4,5-T were degraded the most; 91% of the 2,4,5-T carbon was given off as CO_2 and 80% of picloram carbon was given off as CO_2. Malathion, trifluralin, paraquat, DDT and dieldrin were also slightly biodegraded.

Of pesticide formulations tested, only soils treated with carbaryl had higher bacterial population than the soil samples. All other pesticides formulations reduced the number of bacteria. Malathion, DNBP, zineb, and picloram severely inhibited the bacteria (Stojanovic et al., 1972). The fungi were inhibited by 9 pesticides and 2 pesticides, PMA and DNBP, completely eliminated the fungi from the soil.

The seven mixtures of pesticides studied by Stojanovic et al. (1972) and the amount of CO_2 evolved from each analysis are listed below:

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 287)
U.S. GOVERNMENT PRINTING OFFICE
TYPING GUIDE SHEET

	Mixture	Percent
1)	2,4-D and 2,4,5-T	70
2)	Malathion, trifluralin and 2,4,5-T	45
3)	Paraquat, DSMA, diuron and zineb	20-30
4)	DDT, dieldrin, and carbaryl	20-30
5)	Carbaryl, vernolate, and PMA	20-30
6)	Picloram, dicamba, and dalapon	0
7)	DBCP, bromacil, DNBP, and atrazine	0

Stojanovic et al. (1972) concluded that mixtures of pesticide formulations were more likely to be biodegraded than single compounds if at least one of the pesticides in the mixture was relatively easily biodegraded. Of the 7 formulation mixtures, No. 3 and No. 5 were degraded by bacteria; the others inhibited bacterial growth.

Stojanovic et al. (1972), found that the streptomyces and fungi were more resistant to the pesticide mixtures than the bacteria. Mixtures Nos. 1,4, and 6 inhibited growth of streptomyces. However, a 5-15 fold increase in the growth of streptomyces occured with the other mixtures. The only mixture that inhibited fungal growth was No. 4.

Although a number of researchers have found that many pesticides are degraded by microorganisms, other researchers have stated that many pesticides persist in the soil, some for a number of years, as shown in Table 41.

The main research emphasis on microbial degradation in soils has been aimed at the persistant pesticides. However, Tiedje (1977) has reported on the influence of environmental parameters on EDTA biodegradation in soils. He applied ^{14}C-EDTA in concentrations ranging from 440 to 1000 ppm to a variety of soils collected at various times of the year.

EDTA biodegradation occurred in all soils as shown in Table 42, although the subsoil samples had only a minimal amount of degradation. The higher concentrations (500 and 100 ppm) initially were inhibitory, but eventually stimulated biodegradation. Tiedje (1977) suggests that because of chelating action, the 1000 ppm concentration increased the availability of soil organic matter for microbial attack.

An increase in incubation temperature of the soil and EDTA, from 10° to 30°C resulted in an increase in rate of degradation, as evidenced by the percent recovery of $^{14}CO_2$. Tiedje (1977) suggested that a thermotolerant population was selected which catalyzed the EDTA degradation. Tiedje (1977) also reported that samples collected in the winter yielded the highest rate of degradation; those

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN: EPA FORM 287)
TYPING GUIDE SHEET

TABLE 41. PERSISTENCE OF PESTICIDES IN SOIL

Name	Persistence	Reference
Aldrin	>15 yr	Lichtenstein *et al.* (1971)
Chlordane	>15 yr	Stewart and Chisholm (1971)
DDT	>15 yr	Stewart and Chisholm (1971)
Dicamba	4 yr	Burnside *et al.* (1971)
Diuron	>15 months	Weldon and Timmons (1961)
2,4-D	>103 days	Burger *et al.* (1962)
Endrin	>14 yr	Nash and Woolson (1967)
Heptachlor	>14 yr	Nash and Woolson (1967)
Lindane	>15 yr	Lichtenstein *et al.* (1971)
Parathion	>16 yr	Stewart *et al.* (1971)
PCP	>5 yr	Hetrick (1952)
2,4,5-T	>190 days	DeRose and Newman (1947)
Toxaphene	>14 yr	Nash and Woolson (1967)

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 287)
TYPING GUIDE SHEET

TABLE 42. BIODEGRADATION OF ^{14}C-CARBOXYL EDTA (4 PPM) IN A VARIETY OF SOILS (TIEDJE, 1977)

Sample Source	Soil	Use	pH (H_2O)	Rate of EDTA degradation	Total $^{14}CO_2$ 15 weeks	45 weeks
				§ 4 weeks		
Michigan‡	Houghton muck	Vegetables	5.9	2.6	10.5	
	Houghton muck subsoil	-	6.1	0.8	3.5	
	Miami sandy loam (sl)	Pasture	6.0	10.0	44.5	
	Brookston loam (l)	Forest	6.8	11.0	43.5	65.0
	Conover (sl)	Soybeans	6.7	12.2	46.0	70.5
	Spinks loamy fine sand(lfs)	Corn	6.4	11.3	32.0	
	Spinks lfs subsoil	-	6.3	0.6	3.5	
	Spinks (sl)	Forest	4.6	-	19.0	
	Conover (sl)	Corn	7.4	6.7	27.5	
	Conover (sl) subsoil	-	7.6	0.8	4.0	
Florida	Rockdale	Tropical Fruits	7.9	9.0	34.0	
Idaho	Portneuf sicl	Sugar Beets	7.9	1.8	9.5	
California	Yolo I	Cereals beans	7.6	3.0	13.0	
Kansas	Maron I	Sorghum	5.9	1.9 (4.2)§	13.0	

†Rate calculated from best linear fit of plotted values in the 5-8 week incubation period.

‡Samples collected in February.

§Accelerated rate of degradation which began at 10 weeks of incubation.

collected in the summer had the lowest. He suggested that the organic material that became available for microbial attack due to periods of freezing and thawing accounted for the increase in degradation in the winter-collected samples.

From the data found in the literature review, it appears that microbial degradation is a viable method for removal of hazardous materials, especially if conditions are optimized in favor of biodegradation. Three techniques for biodegradation of spilled hazardous materials are possible:

- optimization of conditions for degradation by existing soil organisms
- application of a variety of organisms, *e.g.* sewage effluent
- application of microorganisms known to metabolize the spilled material.

Optimization of conditions for degradation by existing soil microorganisms can take the form of addition of water, nutrients, changing pH or providing additional aeration by plowing. All of these factors have been shown to affect the ability of soil microorganisms to degrade hazardous chemicals.

If the natural surviving soil microorganisms are killed, suitable organisms can be provided in order to bring about degradation of the chemical. These organisms can be applied as mixed cultures, adapted mixed cultures or as a single culture known to be capable of degrading the chemical. However, additional research is necessary in order to provide a methodology that will be applicable on a wide scale.

Uptake and Effects of Chemicals on Plants

Organic Chemicals--

The effect of various herbicides, fungicides and related chemicals on plant activity has been investigated in various studies. The objective of these studies was to achieve a better understanding of the ecological impact of these substances in the environment. Zutshi and Kaul (1975) studied the cytogenetic activity of several fungicides in barley (*Hordeum vulgare* and *Vicia faba*). Barley seeds were soaked in each test solution, washed and planted in glass Petri dishes. Seedling injury was calculated by the height attained by the first leaf. The results of various fungicide treatments on seed germination, seedling injury and genetic aberrations in barley are listed in Table 43. These data indicate that Copperson Bernlate, Lonocol, Dexon, Ceresan, Hexason and Karathane are the most injurious to seedlings. The secondary roots of *Vicia faba* were exposed to the more toxic fungicides. The results of these treatments are presented in Table 44. Of the fungicides tested, Dexon caused the greatest number of cellular aberrations.

The use of herbicides such as 2,4-D (2,4-dichlorophenoxyacetic acid) in orchards is common practice. However, this herbicide can damage trees if sprinkler irrigation follows soon after 2,4-D application. Larsen (1974) reported injury to 8 year old pear trees due to 2,4-D application to a grass cover

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 287)
TYPING GUIDE SHEET

TABLE 43. EFFECTS OF VARIOUS FUNGICIDE TREATMENTS ON SEED GERMINATION, SEEDLING INJURY AND CHROMOSOME ABERRATIONS IN BARLEY (ZUTSHI AND KAUL, 1975)

Fungicides	Germination % of Control	Seeding % Injury	Chromosome Aberrations/cell Bridges	Chromosome Aberrations/cell Fragments	% Abnormal Cells
Control	100.00	-	-	-	1
Copper Compounds	-	-	-	-	-
Coppersan (45.5)	64.30	52.23	0.08	0.13	13
Copper Dust	93.00	8.45	0.00	0.01	1
Copper Blue	96.66	6.21	0.00	0.01	1
Carbamates	-	-	-	-	-
Benlate	78.56	46.76	0.04	0.75	41
Lonocol	81.90	34.57	0.02	0.27	27
Fermate	73.46	19.89	0.01	0.05	5
Cuman	86.33	22.38	0.01	0.03	4
Dithane (M_{45})	92.00	12.43	0.00	0.03	3
Dithane (Nebam)	95.66	10.94	0.00	0.02	-
Sulphur Compound	-	-	-	-	-
Dexon	73.56	53.23	0.04	0.063	45
Mercury Compounds	-	-	-	-	-

(continued)

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN/EPA FORM 287)
TYPING GUIDE SHEET

TABLE 43 (continued)

Fungicides	Germination % of Control	Seeding % of Injury	Chromosome Abberations/Cell		% Abnormal Cells
			Bridges	Fragments	
Hexason	73.40	24.62	0.05	0.12	15
Cerasan	73.66	42.03	0.06	0.18	16
Amide	-	-	-	-	-
Orthocide + (60)	93.66	11.93	0.01	0.07	5
Orthocide + (75)	90.70	9.94	0.01	0.04	3
(Captan)	-	-	-	-	-
Carbonate	-	-	-	-	-
Morestan	90.33	22.37	0.05	0.11	11
Crotonate	-	-	-	-	-
Karathane	27.45	50.74	0.11	0.36	22

TABLE 44. THE TYPES AND FREQUENCY OF CHROMOSOMAL ABERRATIONS PRODUCED BY 30 MIN TREATMENT WITH VARIOUS FUNGICIDES IN THE SECONDARY ROOTS OF VICIA FABA (ZUTSHI AND KAUL, 1975)

Treatment	Recovery Interval in Hours	Abberration/100 Cells: Chromatid Breaks	Isolocus Breaks	Chromotid Exchanges	Various Others	Abberrations Per Cell
1 Lonocol	24	6	14	0	12	0.32
(0.025%)	48	3	26	3	19	0.51
2 Benlate	24	9	28	0	6	0.43
(0.025%)	48	18	60	9	16	1.06
3 Dexon	24	6	53	16	30	1.05
(0.025%)	48	9	56	9	26	1.00
4 Cerasan	24	6	14	14	14	0.48
(0.025%)	48	8	26	18	12	0.64
5 Hexason	24	3	14	6	2	0.25
(0.025%)	48	1	20	8	6	0.35
6 Morestan	24	1	10	0	8	0.19
(0.025%)	48	0	14	14	4	0.32
7 Coppersan	24	4	20	11	11	0.46
(0.025%)	48	6	14	10	14	0.44
8 Karathane	24	2	6	6	12	0.26
(0.025%)	48	4	9	9	13	0.35

crop adjacent to a pear tree row followed by sprinkler irrigation within 24 hours. Fall leaf abscission was inhibited and foliage development was abnormal the following spring.

The effect of crude oil on the growth of corn (Zea mays L) was investigated by Udo and Fayemi (1975). Germination and yields were drastically reduced as levels of crude oil increased (see Figure 19). At 4.2% crude oil by weight of soil, the average reductions were 50% and 92% in germination and yield, respectively. Poor growth was attributed to:

- suffocation of the plants
- interference with plant-soil-water relationships
- toxicity from sulfides and excess magnesium during growth
- decomposition of the hydrocarbons

Metals--

Vegetation is an intermediate reservoir through which trace metals move to other living organisms. The quantities and forms of trace metals that enter, are distributed within the plant reservoir, and eventually migrate to other locations in the ecosystem, are of basic importance. Metals may be localized in roots and stem, or they may accumulate in non-toxic form. In some plants potentially toxic metals are bound at the cell walls of roots and leaves thereby protecting sensitive intracellular areas. A diagram of trace-metal cycling in a plant-environment system is presented in Figure 20.

Berry (1977) studied the effects of acute toxic levels of copper and zinc on germination and growth in lettuce seeds. Dose response curves were plotted of root length vs. heavy metal concentration. These curves are shown in Figure 21. Root length was reduced 50% by heavy-metal concentrations of 115 microequivalents/liter for zinc and 16.5 microequivalents for copper. Acute toxicity in lettuce (the concentration at which these metals become toxic to seedling development) was 66 microequivalents/liter for zinc and 15.7 microequivalents/liter for copper.

The ability of bush-bean plant roots (Phaseolus vulgaris L.) to act as a barrier to translocation of certain metals was investigated by Wallace and Romney (1977). The plants were grown in a greenhouse in 3700 ml nutrient solution for 12-21 days. They were then transplanted to solutions containing various concentrations of heavy metals. Reasonably uniform distribution between roots and shoots occurred for zinc, manganese, nickel, lithium and boron. Iron, copper, aluminum, cadmium, cobalt, and molybdenum were usually distributed in roots but some large quantities occurred in shoots. Lead, tin, titanium, silver, chromium, vanadium, zirconium and gallium were found primarily in the roots. Specific distribution of some trace metals among Phaseolus vulgaris L. plant parts are listed in Table 45.

The influence of diammonium phosphate and pH on the uptake of heavy metals (chromium, copper, nickel, lead and zinc) by corn (Zea Mays L.) was studied by

BEGIN FIRST LINE OF TEXT HERE
TYPING GUIDE SHEET
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD BEGIN SECTIONS HERE

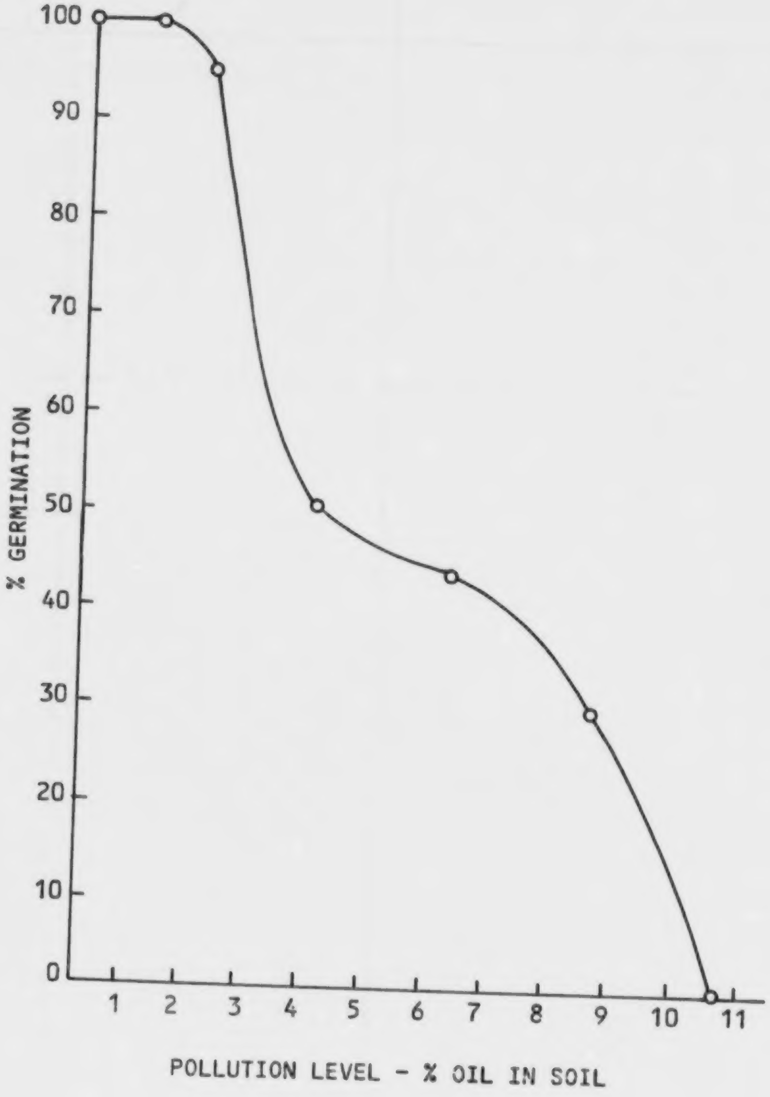


Figure 19. Effect of the level of crude oil addition to the soil on the germination of maize grains (Udo and Fayemi, 1975).

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

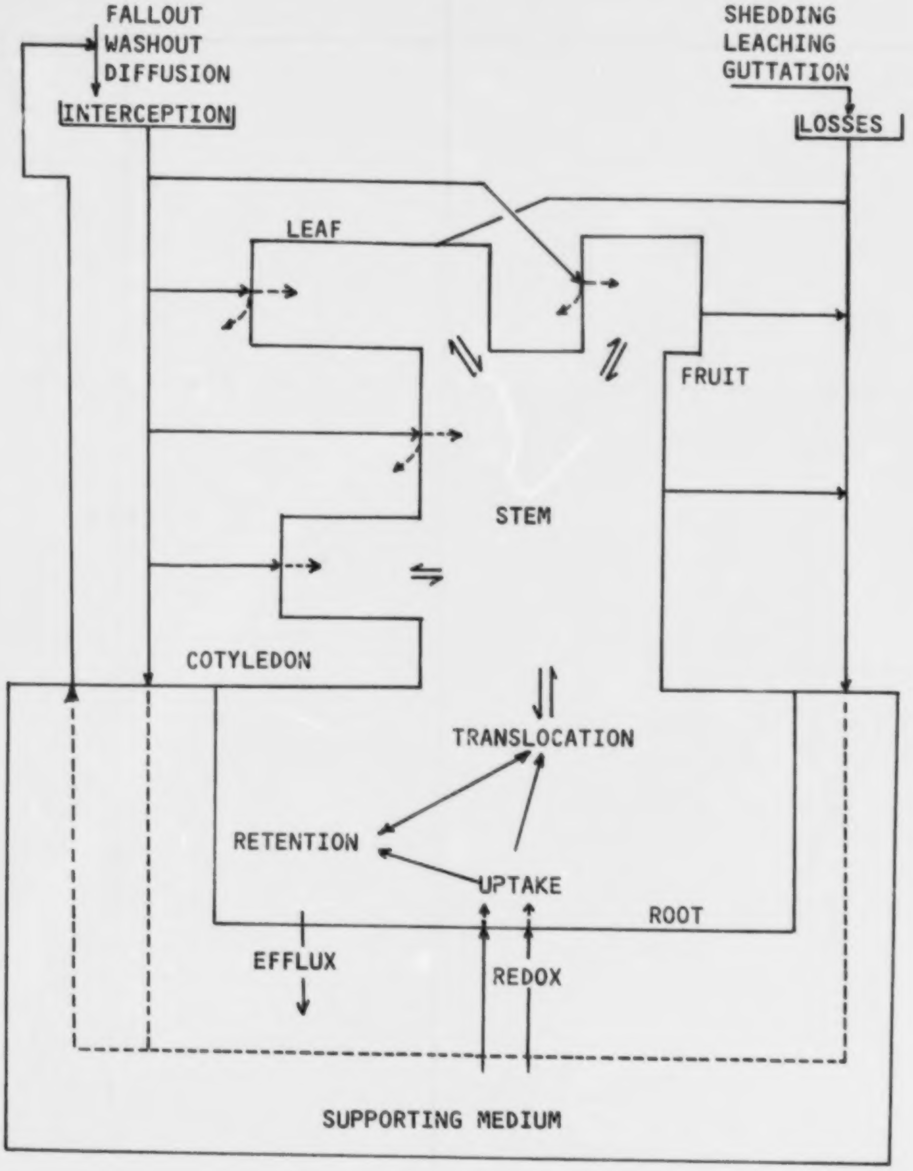

FALLOUT
WASHOUT
DIFFUSION
INTERCEPTION
SHEDDING
LEACHING
GUTTATION
LOSSES
LEAF
FRUIT
STEM
COTYLEDON
TRANSLOCATION
RETENTION
UPTAKE
ROOT
EFFLUX
REDOX
SUPPORTING MEDIUM

Figure 20. Diagram of trace-metal cycling in a plant-environment system (Tiffin, 1977).

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
DROPPED HEAD BEGIN SECTIONS HERE
CENTER OF PAGE
TOP OF IMAGE AREA
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

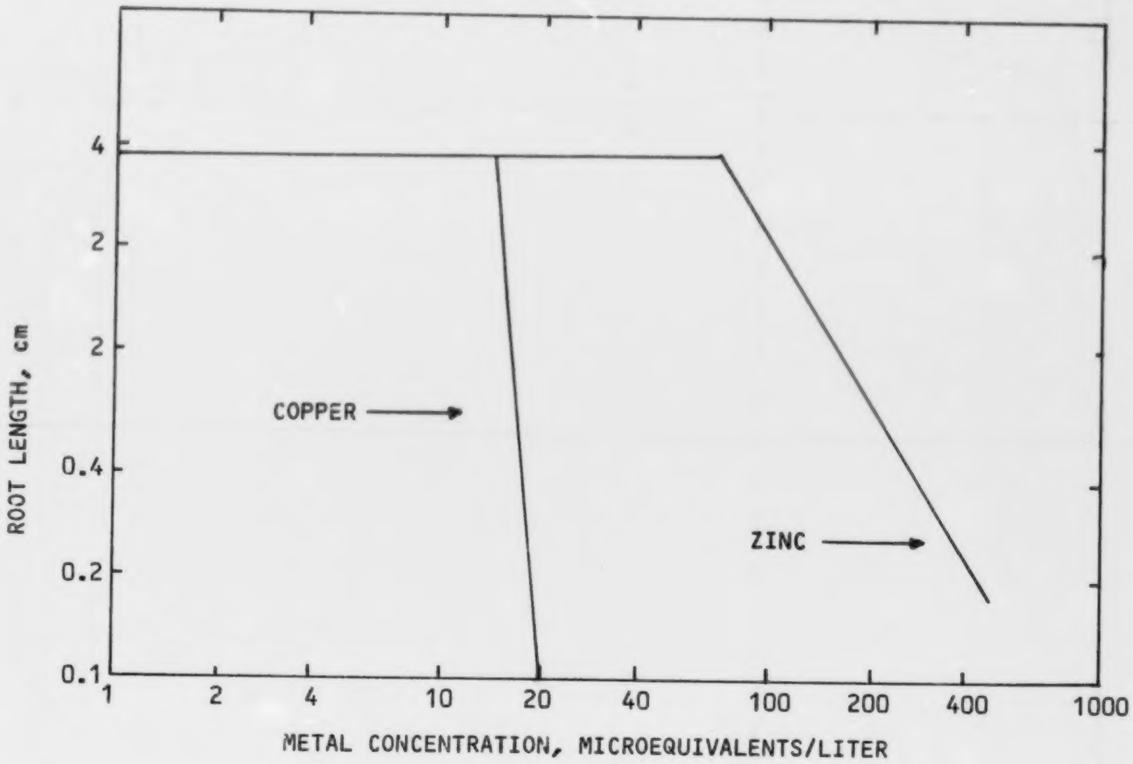


Figure 21. Dose-response curves of seedling lettuce subjected to acute zinc and copper toxicity (Berry, 1977).

EPA-287 (Cin.)
(4-76)

TABLE 45. TYPICAL DISTRIBUTION AMONG PLANT PARTS OF PHASEOLUS VULGARIS L. OF SOME TRACE METALS (DRY-WEIGHT BASIS) (WALLACE AND ROMNEY, 1977)

Plant Part	Aluminum	Nickel	Cobalt	Lead	Iron	Copper	Manganese	Zinc	Molybdenum
With Regular Solution Culture									
Roots	70	2	3.5	12	3900	44	185	124	35
Stems	4	6	0.3	5	74	7	16	42	21
Leaves	10	6	0.4	0					
Lower Leaves					335	17	116	85	16
Upper Leaves					213	11	54	46	9
With Elevated Levels in Solution Cultures									
Roots	276	400	300	200					
Stems	6	400	178	15					
Leaves	16	400	139	9					
With Elevated Supply of Specific Trace Metals									
Roots					5000	269	711	350	
Stems					110	69	460	324	
Lower Leaves					710	95	772	303	
Upper Leaves					358	86	605	244	
2% Vegetative Yield Depression for Elevated Supply									
Whole Plant	9	99	57	13	50	71	52	29	

Mortvedt and Giordano (1977). Their results are presented in Table 46. In general, heavy metal uptake is favored by acidic soil. The presence of diammonium phosphate also tends to increase plant uptake of heavy metals.

Vegetables grown in Sango silt loam (pH 6.4) amended with anaerobically digested sludge containing trace heavy metals were studied for metal uptake by Giordano and Mays (1977). Sludge from Decatur and Tuscumbia, Alabama was used. The results of this study are presented in Table 47. Yields of most vegetables were unaffected by applied sludge. Tomato and squash yields increased significantly. Zinc and cadmium tended to accumulate in radish and turnip roots. Lettuce was the greatest accumulator of zinc, cadmium and copper among the leafy vegetables. Beans, okra pods, tomato, pepper and squash fruits contained less heavy metal than did the vegetative tissue.

The data gathered in the literature survey indicates that uptake of chemicals, especially metals, does occur in plants. This uptake can be aided by controlling soil pH and phosphate content. Thus, the use of harvestable vegetation to concentrate metals from the soil appears to be a viable technique for restoration of land damaged by spills of heavy metals. Sufficient information is not available to assess the utility of plants for uptake and degradation of organic chemicals.

Revegetation--

The information available on revegetation of spill damaged areas is sparse. However, insight into the problems associated with revegetation of toxic soil can be obtained from experiences associated with restoration of strip mining lands.

Many problems are created by surface mining for coal. The aesthetic beauty of the area is destroyed after coal stripping. Changes in the physical and chemical properties of disturbed soil often create a hostile environment for seed germination and vegetative growth. Barren areas are subject to sheet erosion which contributes sediment and pollution to surrounding streams.

Revegetation of denuded areas has been a constant problem since the beginning of surface mining. Spoil material is often too toxic for plant life to exist. Methods are being investigated for alleviation of the toxic condition so that vegetation can establish and survive on strip mine waste lands. Techniques are also being devised to revegetate steep outer slopes with grades up to 65%.

In some localities, excellent reclamation work has been done on mined spoils while other areas have been totally neglected. New surface grading techniques required by some states have been introduced with partial success in sedimentation and erosion control. Success or failure is determined by the management received after grading. Fertilization and the planting of trees, shrubs, grasses and legumes on many sites has been hindered by low pH, lack of available plant nutrients, improper selection of adapted varieties, and climatic factors (Bennett et al., 1976). During grading, the soil surface should be left rough, preferably with small furrows crossing the surface horizontal to the angle of the grade. This allows seed and fertilizer to be caught in the furrows and rough surface areas which increases germination and seedling development while decreasing soil and fertilizer losses from erosion.

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 337)
TYPING GUIDE SHEET

TABLE 46. FORAGE YIELDS AND UPTAKE OF PHOSPHORUS AND HEAVY METALS BY CORN AS AFFECTED BY SOIL pH AND INCLUSION OF HEAVY METALS IN REAGENT-GRADE DIAMMONIUM PHOSPHATE (CROP 1.) (MORTVEDT AND GIORDANO, 1977)

Phosphorus applied, mg/pot	Heavy Metals in diammonium phosphate,* ppm	Forage yield, g/pot	Plant uptake of phosphorus mg/pot	Plant uptake, g/pot					
				Zinc	Copper	Cadmium	Chromium	Nickel	Lead
			Acid Soil, pH 5.7						
0	0	7	8	710	56	7	5	7	18
200	0	42	64	910	116	6	24	48	54
600	0	49	190	1003	128	8	25	53	54
200	200	48	73	1008	140	15	23	63	64
600	700	51	200	1023	135	31	24	51	58
200	2,000	46	68	988	147	63	27	46	52
600	2,000	49	127	1142	292	173	28	43	65
200	10,000	45	63	1661	311	390	29	92	47
600	10,000	45	147	1799	404	726	28	119	48
			Limed Soil, pH 7.6						
0	0	6	5	128	37	2	22	10	12
200	0	42	51	399	155	7	23	30	37
600	0	53	145	350	178	10	25	35	39
200	200	42	56	379	167	13	23	32	38
600	200	49	99	277	182	17	31	12	44
200	2,000	37	54	391	186	55	23	25	30
600	2,000	54	121	512	361	103	21	23	46
200	10,000	35	44	495	221	181	20	32	44
600	10,000	49	75	564	369	390	26	33	30

*Zinc, copper, cadmium, chromium, nickel, and lead added as chlorides to diammonium phosphate at the given rate.

TABLE 47. TOTAL YIELD AND CONCENTRATIONS OF HEAVY METALS IN VEGETABLES, AS AFFECTED BY SLUDGE TREATMENT, 1974 (GIORDANO AND MAYS, 1977)

Species and Sludge Treatment	Yield kg/plot	Fruit or root concentration, ppm				Leaf concentration, ppm			
		Zn	Cu	Cd	Ni	Zn	Cu	Cd	Ni
Beans									
None	7	21	7.9	0.04	1.3	40	6.0	0.46	2.6
Decatur	7	31	7.6	0.23	2.7	179	7.8	1.70	3.5
Tuscumbia	6	28	7.4	0.07	1.8	95	5.8	0.55	2.4
Okra									
None	12	40	9.2	0.13	0.7	41	6.9	0.59	1.9
Decatur	11	61	9.0	0.60	0.7	94	10.0	2.00	2.8
Tuscumbia	11	43	8.3	0.16	0.7	55	7.1	0.59	1.8
Peppers									
None	23	23	10.4	0.09	1.0	68	19.0	0.71	1.7
Decatur	25	41	13.4	0.40	2.3	143	21.0	2.70	2.7
Tuscumbia	20	31	10.5	0.14	1.6	92	18.0	0.76	2.1
Tomatoes									
None	23	15	3.4	0.12	1.8	49	19.0	0.66	1.5
Decatur	29	24	3.8	0.39	3.3	77	22.0	2.10	2.3
Tuscumbia	30	20	2.9	0.20	0.7	55	18.0	0.75	1.6
Squash									
None	43	47	12.8	0.03	0.9	93	14.0	0.34	1.7
Decatur	67	83	15.3	0.20	2.6	233	19.0	0.63	4.0
Tuscumbia	73	93	12.8	0.15	1.6	226	15.0	0.36	2.2
Turnips									
None	13	39	5.5	0.42	1.8	52	6.3	0.59	2.9
Decatur	14	133	8.9	1.30	2.8	194	9.4	2.60	4.0
Tuscumbia	13	73	6.5	0.42	2.1	96	7.3	0.59	2.9

(continued)

TABLE 47. (CONTINUED)

Species and Sludge Treatment	Yield kg/plot	Fruit or root concentration, ppm				Leaf concentration, ppm			
		Zn	Cu	Cd	Ni	Zn	Cu	Cd	Ni
Radishes									
None	-	48	3.2	0.29	3.0	56	5.5	0.92	3.9
Decatur		149	3.8	0.92	3.7	275	7.5	3.10	6.0
Tuscumbia		121	3.3	0.33	2.6	271	3.8	0.88	5.1
Kale									
None	11					33	6.0	0.63	1.8
Decatur	11					161	8.1	2.30	3.5
Tuscumbia	13					113	7.6	0.63	2.4
Lettuce									
None						71	12.9	1.00	2.2
Decatur						212	22.8	8.60	3.8
Tuscumbia						336	21.0	3.00	3.9
Spinach									
None						168	9.1	1.00	2.3
Decatur						163	12.7	2.80	2.9
Tuscumbia						225	10.0	0.84	2.1

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 287)
TYPING GUIDE SHEET

Various forms of limestone have been used to neutralize acid spoils with great success. The selection of the form of limestone to be used in neutralizing acidic strip mine spoils is based upon the chemical analyses of the spoil material to be amended. Dolomite limestone may be selected in areas lacking magnesium, an element essential to plant life. On acid mine spoils, dolomite has been reported almost as effective as calcite limestone in raising the pH.

Phosphate rock is a good spoil amendment for plant growth under toxic pH conditions (pH 3.5-4.5). Phosphate rock contains approximately 30% total phosphorus with 4 percent available in its natural state. (It also contains 58% calcium oxide and 0.5% magnesium). The acidic spoil will react with the phosphate rock to release some of the components necessary to support vegetation.

An attempt is being made to use waste materials that are creating environmental problems as soil amendments for acid mine spoils. Digested sewage sludge, composted sewage sludge, composted garbage and fly ash are currently being evaluated.

Supplementary nitrogen must be added if vegetation is to be established on spoils with low nitrogen content. Chemical analyses of the spoil material will indicate when elemental deficiencies exist.

Mulching materials are needed to alter the surface microclimate and to help conserve moisture during seedling establishment. Various organic materials have been studied and found to be effective as mulches: pulp, fiber, straw, sawdust, wood chips, cured hay, chemical binding agents and in site mulches. Pulp fiber applied by hydroseeder at the rate of 280-448 kg/ha (500-800 lb/acre) has been moderately effective (Armeger et al., 1976), but the cost is limiting. Straw has been an effective mulch for new seedlings on bare and untilled surfaces. When two to three tons per acre of straw were distributed over the soil surface after seeding, excellent seed germination resulted. Well-weathered sawdust material, that had been leached for a minimum of a year, proved to be a very good mulching material. Fresh sawdust had a tendency to float or move during heavy rains. Sawdust is limited by its availability in the reclamation areas. Wood chips were satisfactory in aiding seed germination but were not as good as straw mulch for establishing Kentucky 31 tall fescue or orchard grass. Bark and wood chips are very bulky and mechanical equipment for application is limited. Cured hay has been used with considerable success. Some hay may contain sufficient grass seed to serve both as a mulch and seed source. Many chemicals have been developed to provide erosion control and soil stabilization for seedling establishment. Data on suitability, availability, and cost of these binders are limited. When used alone, many of these chemicals do not fulfill all purposes of a mulch. Used in conjunction with organic mulches, some chemical binders have improved the stability of the mulch. An economical mulch can be produced by seeding cereal grains or summer annuals as the first crop. Wheat, barley or rye can then be established without mulch in the fall and killed in the spring before maturity while summer annuals are killed by frost in the fall (Armeger et al., 1976).

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 287)
☆ U.S. GOVERNMENT PRINTING OFFICE 1980-660-839
TYPING GUIDE SHEET

BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD; BEGIN SECTIONS HERE

Many studies have been conducted to determine the suitability of various grass species for revegetation of surface mine spoil areas in the eastern United States (Bennett *et al*., 1976). A major problem in the east concerns acidic spoils and high levels of aluminum and magnesium. Species selection is important for adaptation in these areas. Grass species that have shown potential for revegetation in the eastern U.S. include tall fescue, bermuda grass varieties, weeping lovegrass, switch grass, red top, dear tongue, bent grasses, big and little blue stem and commercial varieties of orchard grass, bromegrass, eyegrass and timothy (Bennett *et al*., 1976). Weeping lovegrass and bermuda grass seem to be most adaptable to low pH mine spoils.

The use of legume species on mine spoil areas is very important. They provide a high quality hay, rich in nitrogen and protein, while having a beneficial influence on desirable soil microorganisms that are important in soil transformation. Important legume species that have been studied on acidic strip mine areas in Appalachia include alfalfa (*Medicago sativa*), white clover (*Trifolium repens*), crimson clover (*Trifolium incannatum*), birdsfoot trefoil (*Lotus corniculatus* l.), lespedeza (*Lespedeza sericea*), crownvetch (*Coronilla varia*), hairy vetch (*Vicia villosa*), and red clover (*Trifolium pratense* L.) (Bennett *et al*., 1976).

Revegetation alone does not tend to remove hazardous chemicals from spill damaged land. However, revegetation along with the addition of nutrients and pH adjustment can aid in land restoration by control of erosion, absorption of the toxic chemical, and aiding in the growth of microorganisms capable of degrading the spilled material. Factors which influence the success of revegetation efforts include:

- type of soil and nutrients available
- climatic conditions
- soil flora and fauna
- selection of plant species
- planting methodology
- plant maintenance

These factors are interactive rendering each revegetation project a unique situation. However, revegetation can be very successful if guidelines are established and followed.

Before revegetation efforts are initiated, some preliminary information is needed. This information includes descriptions of the soil and climate. The soil should be characterized according to its physical (texture, structure, porosity, color, water retention and aeration), chemical (toxicity, pH, salinity, cation exchange capacity and available nutrients) and biological properties (population of bacteria, actinomycetes, fungi, algae, protozoa, worms, insects,

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS

PAGE NUMBER
EPA Form 2350-4 (4-80)
(PREVIOUSLY CH. EPA FORM 227)
☆ U.S. GOVERNMENT PRINTING OFFICE 1980-600-639
TYPING GUIDE SHEET

etc.). Climatic conditions which require characterization include temperature, precipitation and wind speed, the soil and the climatic conditions must be matched with the plant species. Care in matching these factors will allow selection of plant species which possess the optimum probability of revegetating the area. However, even with the proper choice of plants, the success of the project depends to a large extent on the planting methodology and continued maintenance of the area.

The next step in the process is the selection of the planting technique. Either seeds or young plants can be used. Both techniques have their pros and cons. Seeds are more readily available, less expensive and require less plant maintenance because plants are naturally conditioned. However, seeds require one to two weeks before germination. This time delay can result in significant soil erosion and dust losses. Germination and survival of the young seedlings is often a problem. Plant patterns are also important. Care must be exercised in order to assure that the plants are properly spaced so that they receive adequate sunlight, have sufficient growing area and are close enough for fertilization and reproduction to occur. Often it is profitable to seed the area with a fast growing grass cover followed by the more permanent vegetation properly spaced.

Maintenance of the area is necessary to insure survival and proper plant growth. Maintenance procedures include application of nutrients to the soil, pH adjustment to combat the continuous deleterious effects of the toxic spill, plowing for soil aeration and watering.

Photochemical and Chemical Degradation--

Photodegradation using solar irradiation is often an overlooked method for detoxifying such compounds as polyhalogenated organics. This method is particularly applicable in clay soils when little soil penetration has occurred and before rains spread the chemical and wash it into the soil. Thus, to be useful, the photodegradation technique requires immediate response.

Photodegradation of polyhalogenated organics requires two things - sunlight and the presence of a hydrogen donor species. The hydrogen donor species can be a light hydrocarbon oil. Olive oil was recommended as the hydrogen donor species to help photodegrade the tetrachloro-dibenzo-p-dioxin spilled in Italy in 1976 (Crosby, 1977). Laboratory studies showed that this dioxin could be rapidly dechlorinated by sunlight if the conditions were optimized. The mechanism is a step-wise dechlorination initiated by the absorption of light from the sun. The resulting dechlorinated compound is relatively non-toxic and can be biodegraded by microorganisms.

Sahai and Chauhan (1977) discussed several classes of pesticides which could be photodegraded. The primary degradation reaction that occurred was the replacement of a halogen group on an aromatic ring by a hydroxyl group. Hautala (1978) examined the degree of photolysis of three pesticides; 2,4-D, Parathion and Sevin. He found that the photo decomposition of 2,4-D was a slow process. Sevin degradation was catalyzed by the presence of detergents in the soil and this pesticide could be rapidly degraded to 1-naphthol. The photodegradation of parathion was found to be inconsistent and could not be correlated to soil type, soil moisture or detergents.

EPA Form 2360-4 (4-80)
(PREVIOUSLY OIN EPA FORM 267)
TYPING GUIDE SHEET

Chemical degradation of hazardous materials can include oxidation, reduction, hydrolysis, isomerization, and polymerization. The major soil characteristics which effect chemical degradation are pH, redox potential, surface acidity and the availability of catalytic sites. Adsorption catalyzed hydrolysis is the major mechanism for the degradation of diazino and some s-triazine herbicides (Leonard *et al.*, 1976). Darnell (1978) examined the use of bromination to reclaim hazardous metals and breakdown persistent organic compounds. Bromine and water, at 300°C, can oxidize a variety of metal compounds and organics. A useable by-product of this reaction is hydrogen.

Huibregtse *et al.* (1978) developed a system to treat land spills by injecting grout into the soil around the spill site to isolate the hazardous material. Then detoxification of the hazardous material can be accomplished by oxidation/reduction, neutralization, precipitation or polymerization. Tests were conducted on sand and clay soils contaminated with copper sulfate or sodium hypochlorite. The grout was injected around the contaminated soil. The contaminated soils were then treated to precipitate copper or to oxidize the sodium hypochlorite. In these tests, 70-99 percent of the copper was removed and 58-100 percent of the sodium hypochlorite was oxidized.

Chemical and photochemical degradation can be useful in restoration of spill damaged land. However, criteria must be established for the applicability of these techniques to spill clean-up and land restoration. These criteria can then be used by the on-site spill response coordinator to decide if a chemical or photochemical technique is applicable to a specific spill situation.

BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD. BEGIN SECTIONS HERE

SECTION 6

SELECTION OF CHEMICALS FOR EVALUATION OF LAND RESTORATION TECHNIQUES

Six organic chemicals and two heavy metal salts were selected for evaluation by the four accelerated restoration techniques. Criteria for selection of the organic chemicals included physical form, function of group, persistence, volatility, water solubility, potential biodegradability, and the annual amount produced and transported in the United States. The organic chemicals selected represented a cross-section of the 271 hazardous chemicals listed in the Federal Register (1978) and a variety of chemical classes. The selection of a wide variety of chemicals with different functional groups was deemed necessary in order to demonstrate biological techniques for restoration of spill-damaged lands which would have broad applicability in the field. In this way results from the experiments would have a larger inference space than if only two chemicals were tested by all the techniques. A draw back from this procedure is that the techniques cannot be directly compared to each other. For the heavy metal salts, water solubility and toxicity were the primary consideration for selection.

The chemicals selected for the simulated spills and the spill restoration methods evaluated are presented below:

Technique	Chemical
I. Enhancement of microbial degradation by indigenous organisms	chlorobenzene Ethion
II. Addition of mixed microorganisms from primary sewage effluent	formaldehyde aniline
III. Addition of selected microbial cultures	dinitrophenol chlordane
IV. Selective absorption by harvestable plants	lead nitrate cadmium nitrate

For Technique I, chlorobenzene and Ethion were chosen for several reasons. Monochlorobenzene is one of several compounds on EPA's hazardous materials list

BEGIN LAST LINE OF TEXT
3/8"
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS

PAGE NUMBER
EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 337)
U.S. GOVERNMENT PRINTING OFFICE
TYPING GUIDE SHEET

that has limited water solubility, a high vapor pressure, low soil adsorption and is biodegradable. The U.S. production capacity for monochlorobenzene is 318 million kilograms (700 million pounds) per year (SRI, 1979). Monochlorobenzene is listed in the Coast Guard's CHRIS list of hazardous chemical data and as a hazardous material by the EPA (Federal Register, 1978). Monochlorobenzene is designated as a category B substance by EPA, i.e., any discharge or spill greater than 45.4 kg is harmful to the environment. Ethion is an organophosphorus insecticide produced by FMC Corporation. Ethion is a moderately persistent, relatively water-insoluble compound that can be used on 37 different food crops, cotton, sorghum and other plants. It was anticipated that these chemicals would be a good test of the ability of indigenous organisms to adapt to and degrade a spilled chemical.

Formaldehyde and aniline were evaluated in Technique II. Formaldehyde is a high-use, high-production chemical in the U.S. The total U.S. production capacity is 4116 million kilograms (9074 million pounds) per year (SRI, 1979). For aniline, the U.S. production is approximately 499 million kilograms (1100 million pounds) per year. Preliminary tests showed that the addition of formaldehyde or aniline to soil eradicated the soil microorganisms. If very few indigenous microorganisms are present in the soil, very little biodegradation will occur. Therefore, the addition of primary sewage effluent would tend to replenish the soil bacteria population and potentially lead to the degradation of the compound.

For Technique III, chlordane and dinitrophenol were selected. Chlordane is a chlorinated pesticide and is persistent in the environment. Dinitrophenol is used in the production of dyes and preserving timber. Dinitrophenol is also a difficult compound to degrade due to its structure. Treatment of spilled chemicals with adapted/mutant bacteria is the most involved, time-consuming, and expensive technique studied. This technique was used on chlordane and dinitrophenol because they were the most difficult chemicals to degrade.

In Technique IV, the absorption by harvestable plants, lead nitrate and cadmium nitrate were selected. Lead was used because it is a prevalent and highly used heavy metal. Cadmium was selected because of its high toxicity.

SECTION 7

EXPERIMENTAL METHODOLOGY

ENVIRONMENTAL CHAMBER CONSTRUCTION

For the restoration of spill-damaged lands study, two 2.7 x 5.8 m greenhouses were used. Each greenhouse contained nine enclosed environmental chambers. The environmental chambers were constructed in groups of three with each group supported by a wood frame. A diagram of three environmental chambers is shown in Figure 22. The chambers were constructed of 0.6 cm extra strength glass glued together with GE Clear Silicone Sealer. Each environmental chamber had the following dimensions:

length - 87 cm

width - 87 cm

height - 70 cm

Each environmental chamber had a cover of 0.6 cm glass. To provide a resting place for the cover, the inside of the tops of the chambers were framed with 2.5 cm x 2.5 cm lumber. The lumber was coated with Thompson's Water Proof Sealer to prevent absorption of water or chemicals. The top of the frame was coated with GE Clear Silicone Sealer to provide a cushion seal for the glass cover. An RTV mold release compound was applied around the cover edge to prevent the glass from sticking to the frame. This arrangement provided a cushion but not a completely airtight seal for the environmental chamber covers.

A steady flow of fresh air through the environmental chambers was induced by connecting the air exit line from the chamber to a vacuum system. Photographs of the soil chambers and the air handling system are shown in Figures 23 and 24. Fresh outside-air was admitted into each environmental chamber, recirculated within the chambers by means of a small fan, and then passed through a water cooled condenser, a carbon filter, a sodium hydroxide bubbler and out through the vaccuum pump. The air system permitted all airborne chemicals to be collected for analysis.

A liquid drainage hole was drilled in the glass bottom of each environmental chamber. This hole was plugged with a one-hole neoprene stopper fitted with a glass-teflon stopcock. Thus, any liquid collected in the bottom of the chambers could be drained and analyzed.

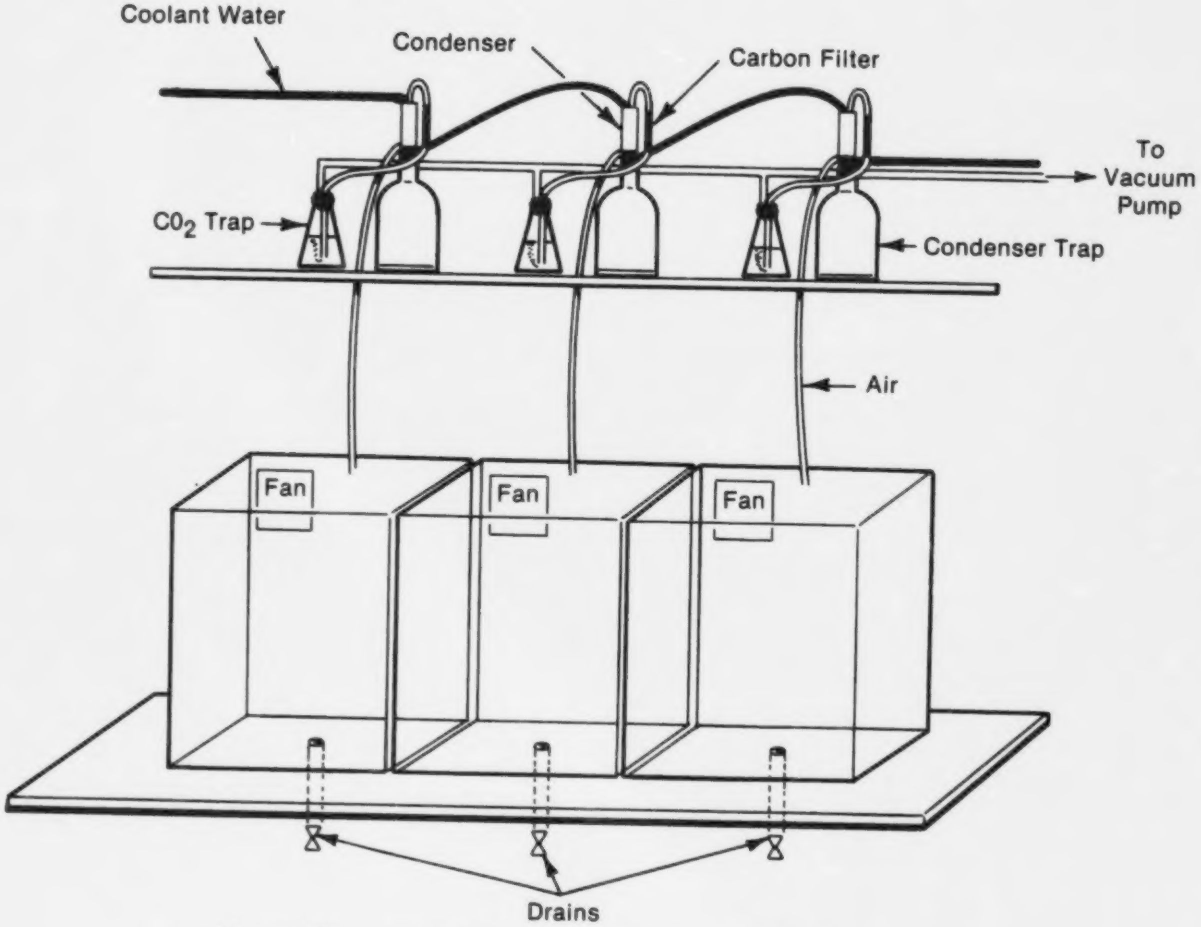

Coolant Water
Condenser
Carbon Filter
To
Vacuum
Pump
CO_2 Trap
Condenser Trap
Air
Fan
Fan
Fan
Drains

Figure 22. Set of three environmental chambers.

Figure 23. Environmental chambers.

Figure 24. Water cooled condenser, carbon filter and sodium hydroxide bubbler from spill chamber.

Two and one-half cm of sand, then 5 cm of gravel and another 2 cm of sand were placed in the bottom of each chamber. Approximately 30-45 cm of soil were then placed in the chambers; high-organic soil in 3 chambers, sandy-loam in 3 chambers, and clay in the remaining 3 chambers. Once the chambers were filled with soil and packed down, the soils were seeded with perennial rye grass and allowed to equilibrate for 3 weeks.

During the application of the spill material, the operators were outfitted with disposable lab coats, gloves, hats and booties. Each operator wore air tight goggles and a Wilson 1200 Basic Face Piece respirator with R-21 organic vapor filters. Once the material was applied to the soil, the chambers were closed and the vacuum pump system put into operation. The chambers were monitored visually every few hours. Core samples were taken at 24 and 48 hours after the spill.

Planters, 45 cm in diameter and 45 cm high, were used to study the uptake of heavy metals by harvestable plants. A diagram of the planters and the experimental treatments are presented in Figure 25. Twelve planters were used for each metal. Three soils were used in the test: organic, sandy-loam and clay. Four planters were used for each soil. For each soil, one planter acted as a control and the other three received the heavy metal contamination.

CHEMICAL SPILLS IN ENVIRONMENTAL CHAMBERS

Before each spill, soil samples were collected to measure microbial levels, pH, percent moisture and other chemical parameters.

Monochlorobenzene

The monochlorobenzene spill material was prepared by the addition of 1 mCi of labelled monochlorobenzene to 18 liters of unlabelled compound. The ^{14}C labelled monochlorobenzene was purchased from California Bionuclear. This compound was labelled uniformly at the ring positions. The unlabelled monochlorobenzene was purchased from Fisher Scientific and had a purity of 99+%.

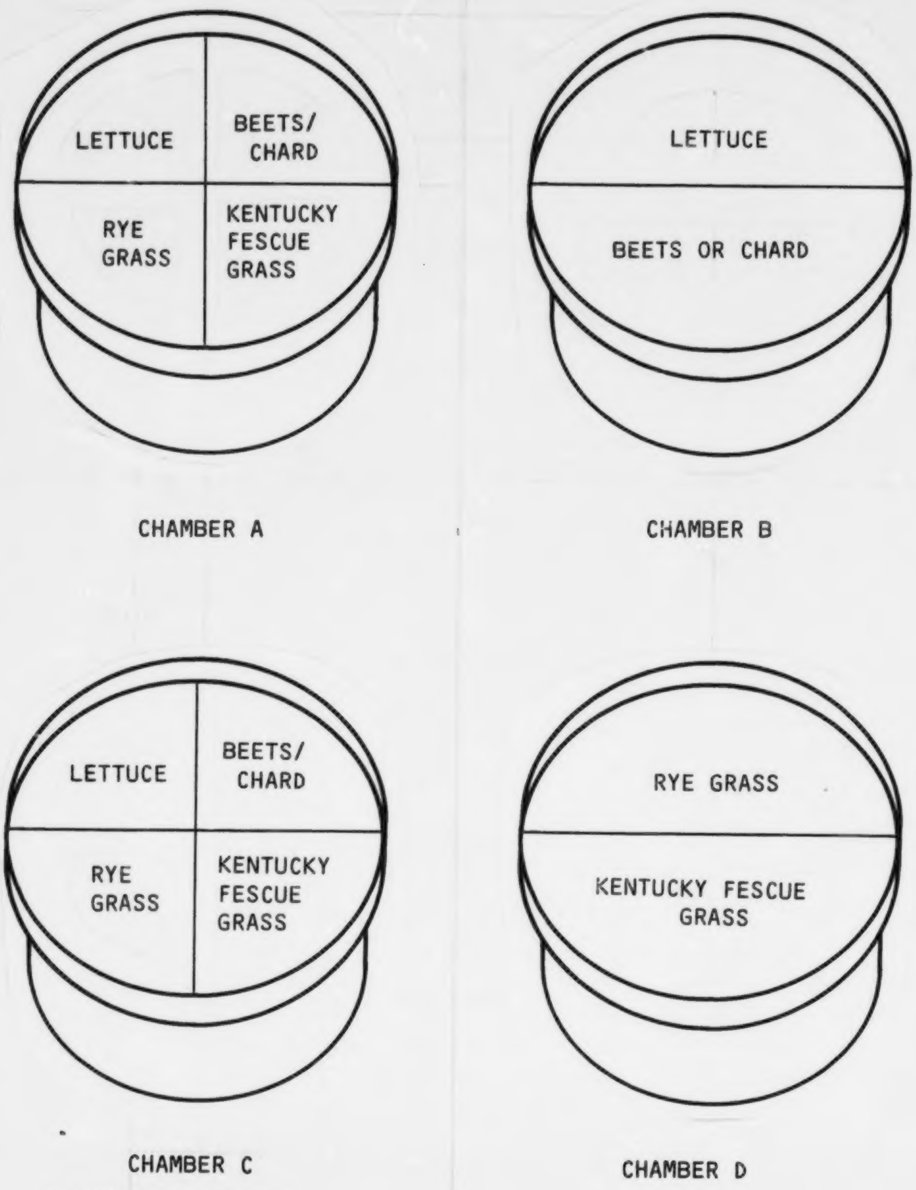
Two liters of the labelled-unlabelled monochlorobenzene mixture were spread evenly over each chamber. A water sprinkling can was used to spread the chemical over the soil to simulate the hazardous spill. Each environmental chamber received 0.292 g of monochlorobenzene per square cm of soil surface; a total of 111 μCi of ^{14}C per chamber.

Ethion

The Ethion was prepared for the simulated spill in the environmental chambers by adding 1 mCi of ^{14}C labelled Ethion to 18 liters of technical grade Ethion. Both the technical grade and ^{14}C labelled Ethion were supplied by FMC Corporation. The ^{14}C labelling was on the backbone carbon ($-S^{*}CH_2-S-$).

Two liters of the Ethion were spread evenly over each chamber with a water sprinkling can. Each environmental chamber received 0.26 g of Ethion per sq cm of soil surface and a total of 111 μCi of ^{14}C.

BEGIN FIRST LINE OF TEXT HERE
TYPING GUIDE SHEET
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD. BEGIN SECTIONS HERE


LETTUCE
BEETS/ CHARD
RYE GRASS
KENTUCKY FESCUE GRASS
CHAMBER A
LETTUCE
BEETS OR CHARD
CHAMBER B
LETTUCE
BEETS/ CHARD
RYE GRASS
KENTUCKY FESCUE GRASS
CHAMBER C
RYE GRASS
KENTUCKY FESCUE GRASS
CHAMBER D

CHAMBER TREATMENTS
A - CONTROL - NO METAL, pH ADJUSTED
B + D - METAL ADDED, pH ADJUSTED
C - METAL ADDED, pH ADJUSTED, CHELATING AGENT ADDED

Figure 25. Experimental design for plant uptake studies.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

Formaldehyde

The formaldehyde spill material was prepared by adding 2 mCi of ^{14}C labelled formaldehyde to 18 liters of a 37-40% aqueous formaldehyde solution. The ^{14}C labelled formaldehyde was purchased from Amersham. The unlabelled formaldehyde was purchased from Textile Chemical Company.

The hazardous spill was simulated by spreading two liters of formaldehyde evenly over the soil in each chamber with a water sprinkling can. Each chamber received 0.11 g of formaldehyde per square cm of soil surface and a total of 222 μCi of ^{14}C per chamber.

Aniline

Aniline, for the simulated hazardous spill was prepared by adding 1 mCi of ^{14}C uniformly ring labelled aniline to 18 liters of aniline. The ^{14}C labelled aniline was purchased from California Bionuclear. The unlabelled compound was obtained from Fisher Scientific. Each environmental chamber received 0.25 g of aniline per square cm of soil surface and a total of 111 μCi of ^{14}C per chamber.

Chlordane

Technical grade, 21% emulsifiable concentrate, was used for the chlordane spill. Carbon-14-labelled chlordane was synthesized from ^{14}C uniformly ring labelled hexachlorocyclopentadiene. Only 100 μCi of ^{14}C chlordane were available, therefore, only the sandy soil received the labelled compound. Each sandy soil chamber received 25 μCi of ^{14}C labelled chlordane. The technical grade chlordane was supplied by the Velsicol Company.

Two liters of a 1:1 mixture of chlordane and water were spread evenly over each chamber using a sprinkling can. Each chamber had surface chlordane levels of 0.2 g per square cm.

2,4-Dinitrophenol

The dinitrophenol spill was simulated by sprinkling 500 g of 2,4-dinitrophenol (powder) into the soil surface in each chamber to yield a surface 2,4-dinitrophenol concentration of .07 gm per square cm.

Cadmium Nitrate

Two hundred and fifty (250) ml of an aqueous solution of cadmium nitrate (6.8 g/1) were sprinkled on the soil surface of three of the four planters for each soil type. This simulated spill yielded cadmium levels in the soil ranging from 100-200 ppm.

Lead Nitrate

The simulated spill of lead nitrate was conducted in the same manner as described for cadmium nitrate. The spill solution contained 9.2 g of lead. Lead concentrations in the soils ranged from 100-150 ppm after the spill.

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN: EPA FORM 287)
TYPING GUIDE SHEET

LAND RESTORATION TECHNIQUES

Land Restoration-Technique I

The ability of indigenous microorganisms, that survive the effects of a hazardous chemical spill, to degrade the spilled material was evaluated in Land Restoration Technique I. The microbial population remaining after the spill was stimulated with nutrients (treatment 1) or with nutrients coupled with aeration of the soil (treatment 2). The chemicals used for the Technique I experiments were monochlorobenzene and Ethion.

The restoration treatment -1 and -2 were applied to the soils 48 hours after the spill. The initial treatments for the two chemical spills were the same. For each of three different soil types, (each soil type was used in 3 chambers), one chamber served as a control (untreated), another chamber received treatment-1 and a third chamber received treatment-2. The control and treatments-1 and 2 were randomly assigned to the chambers within soil types. The nutrient used in treatment-1 was Difco Nutrient Broth (8 g/l). Two liters of the nutrient broth were sprinkled over the soil surface to stimulate growth of the residual microbial population. For treatment-2 the same nutrient broth was added to the soil surface.In ddition, the top 5-7.5 cm of the soil were plowed to increase aeration. A garden weasel was used to accomplish the plowing.

After evaluation of the results of treatments-1 and -2 in the Ethion chambers, additional methods of treatment were evaluated. The pH of the soil had decreased to between 4-6 after the Ethion spill. This pH value is too low for growth of many microbes. Soil pH values were therefore increased to approximately 6-7 to optimize growth conditions for the surviving soil microorganisms. Lime was added to the treatment-1 (T-1) and treatment-2 (T-2) chambers on days 46 and 52.

Due to the low solubility of Ethion in water, it is relatively unavailable to microorganisms. Two methods were investigated to increase availability of Ethion to the microbes. On day 95, Tween 80 (a surfactant, Atlas Chemical Industries) and nutrient broth were added to the treated soil chambers. This treatment was followed on day 120 by the application of 50% aqueous ethanol solutions to the soils to help to solubilize the Ethion.

After day 200, small scale experiments were conducted to determine if the hydrolysis of Ethion could be increased by the application of alcoholic sodium hydroxide. These experiments yielded encouraging results and aqueous solutions containing 50% ethanol and 6-8% sodium hydroxide were then applied to the T-2 environmental chambers. Three treatments of 10 liters each of ethanol/sodium hydroxide solutions were applied to the soils from day 210-220.

Land Restoration-Technique II

For Technique II, mixed microbial cultures, obtained from primary sewage effluent, were evaluated for their usefulness in restoring spill damaged land. Primary sewage effluent is readily available and rich in nutrients. Technique II was evaluated on formaldehyde and aniline spills. As in Technique I, restoration treatments were applied to the soils 48 hours after the spill. The control,

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN: EPA FORM 387)
TYPING GUIDE SHEET

treatment-1 and treatment-2 were randomized within soil types. Aniline and formaldehyde were selected for Technique II because they would reduce the indigenous soil microbial populations to low levels. Thus, the effects from the addition of a mixed micobial cultures could be more readily identified.

Formaldehyde Treatment--

The first treatment evaluated on the formaldehyde spill treatment-1 environmental chambers involved the addition of 3.8 liters (1 gallon) of primary sewage effluent to the soil. Treatment-2 environmental chambers received 3.8 liters of primary sewage effluent previously cultured in solutions of 5000 ppm formaldehyde. Thus, organisms that could survive at high formaldehyde concentration increased in number. It was found that the treatment-2 culture contained primarily Pseudomonas sp. These treatments were reapplied to the respective chambers on day 25.

Aniline Treatment--

For the aniline spill, 3.8 liters of primary sewage effluent were added to each of the treatment-1 environmental chambers. The initial step for the treatment-2 environmental chambers was the addition of 2 liters of a 15% solution of hydrogen peroxide to the soil. The hydrogen peroxide was added to oxidize the aniline to a more biodegradable form. One hour after the hydrogen peroxide was added, 4 liters of primary sewage effluent were added to the soil.

On day 12 and day 42, small areas (900 cm^2) of the T-2 chambers were treated with 1 liter of 15% hydrogen peroxide solution. The soils were then plowed. Also on day 42, the T-1 chambers were treated with primary sewage effluent cultured in nutrient broth containing aniline.

On day 96, the T-1 chambers were treated with a mixed culture of microorganisms grown in a solution of aniline, nutrient broth, $MgCl_2$, $Ca(NO_3)_2$ and KH_2PO_4. To provide essential minerals and nutrients for degradation, a solution of $MgCl_2$ (0.2 g/l), $Ca(NO_3)_2$ (3 gm/l), KH_2PO_4 and yeast extract (1 g/l) was applied to the T-1 chambers on days 126 and 154. The T-2 chambers were treated with the same mixture on day 170.

Land Restoration-Technique III

Technique III examined the use of mutant, adapted microbial cultures to treat chemical spills. The two chemicals used in Technique III tests were chlordane and 2,4-dinitrophenol. Once again the treatments were applied 48 hours after the spill and the treatments were randomized within soil types.

Chlordane--

The microorganisms used in the chlordane spill experiment were cultured in a mixture composed of nutrient salts, yeast extract and 21% emulsifiable concentrate technical grade chlordane. The nutrient salts - yeast extract solutions were made up in 4 liter quantities and had the following formulation:

6.4 g K_2HPO_4	1.6 g KH_2PO_4

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 287)
TYPING GUIDE SHEET

2.0 g NH_4NO_3

0.8 g $MgSO_4 \cdot H_2O$

0.92 g $FeCl_3 \cdot 6\ H_2O$

0.86 g $CaCl_2$

4 g yeast extract

Technical grade chlordane acted as the carbon source. The cultures were reinoculated into fresh chlordane, nutrient salts and yeast extract solutions every 7 to 10 days for 2 months. The reinoculation process selected the microorganisms which could adapt to and metabolize technical grade chlordane. Treatment-1 environmental chambers each received 4 liters of microbial culture and nutrient salts mixture. Treatment-2 environmental chambers each received lime, to make the soil basic, followed by the addition of 4 liters of the microbial culture and nutrient salts mixture. The treatments with the microbial culture and nutrient salts mixture were re-applied to the soils on days 8 and 28.

2,4-Dinitrophenol--

For the 2,4-dinitrophenol spill, microorganisms were cultured in a mixture of nutrient salts, yeast extract and 2,4-dinitrophenol. The 2,4-dinitrophenol was the sole carbon source. The cultures were reinoculated in the fresh media every 7 to 10 days for 3 months. This technique selected the organisms which could adapt to and metabolize dinitrophenol. Only six environmental chambers were used in this spill exeriment. Three chambers were controls and three received the microbial treatment. The treatment consisted of first adding 500 g of lime to the chambers to raise the soil pH to basic conditions. The 2-4-dinitrophenol is water soluble under basic conditions and therefore more available to microorganisms. Four liters of the adapted microbial culture, nutrient salts and yeast extract were then added to the lime-treated chambers on day 2 and day 8. No aeration of the soil was conducted.

Land Restoration Technique IV

The fourth land restoration technique evaluated the application of selective absorption of heavy metals by harvestable plants. The heavy metals used in the Technique IV experiments were cadmium and lead. Both heavy metals were applied to soil chambers in the form soluble nitrate salts. Four plants were evaluated for their ability to concentrate metals in the experiment: rye grass, Kentucky fescue grass, lettuce and either beets or chard. The experimental design is presented in Figure 25.

To promote the uptake of the metals by the plants, two treatments were used:

- the soil was made acidic
- the soil was made acidic and disodium EDTA, a chelating agent, was added to the soil

The pH of the soils was adjusted to acidic values with dilute acetic acid. Chamber C (Figure 25) was treated with 400 ml of a 0.1M solution of disodium EDTA. Plant seeds were then added to the soil chambers as shown in Figure 25. Because of poor germination of the beets, Swiss chard was substituted two weeks into the experiment. Soil pH was monitored throughout the experiment and plants were collected from early May until mid-July.

SAMPLING METHODOLOGY

Organic Chemicals

A 30.5 cm corer with a 2 cm diameter used to obtain soil core from the chambers. Core samples were taken according to the following schedule:

- minus 2 days to establish background microbial populations and soil parameters
- spill + 24 hours
- spill + 48 hours
- weekly thereafter

Two core samples were taken per chamber at each sampling time. The location of the core sites was selected from random numbers, i.e., up to 25.4 cm over 40.6 cm. The core samples were separated into 3 levels, 0-5 cm, 5-10 cm, and 10-30.5 cm. The levels from the two core samples in each chamber were pooled for analysis, i.e., the two samples at 0-5 cm levels were put together. Sterile preweighed 250-ml polyethylene beakers with caps were used to store and transport the samples.

The sealed beakers were returned to the laboratory, reweighed and measured amounts of the soil were removed. One gram samples were removed and transferred to 10 ml of sterile water for microbial analysis. Two grams were removed for determination of soil moisture, pH, and % organic analysis, and 0.5 g for radiozonalysis. The remainder of the sample was resealed in the beaker for GC analysis of the chemical.

Heavy Metals

Core samples were collected with a 30.5 cm corer. Two sets of soil samples were taken to establish heavy metal levels in the soil. The plant tissue was collected by cutting the above ground part of the plant with grass clippers. The plant tissue was stored in paper bags until digestion and analysis. Care was taken in harvesting the plants to avoid surface contact of the tissue with the metal containing soil.

ANALYTICAL PROCEDURES

The soil samples from each chamber were analyzed for the following parameters:

- soil pH
- % moisture

BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD. BEGIN SECTIONS HERE
BEGIN LAST LINE OF TEXT
3/8"
PAGE NUMBER
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
EPA Form 2350-6 (4-80)
(PREVIOUSLY CIN. EPA FORM 287)
U.S. GOVERNMENT PRINTING OFFICE: 1980-660-838
TYPING GUIDE SHEET

- % organic matter
- nitrate
- soil bacteria
- soil fungi
- soil ^{14}C activity (except dinitrophenol)
- level of the spill chemical

The procedures used for each of these analyses, as well as those used to determine the chemical content of the traps, carbon filters and the labelled CO_2 content of the NaOH bubblers are described in detail in the following sections.

Soil pH

The pH of the soil was measured by adding 10 ml of distilled water (pH 6.15) to the soil sample and stirring for 30 minutes. The soil was allowed to settle and the pH read using a Orion 399A meter with a 91-04 electrode standardized at pH 4.01 and 9.18.

Percent Moisture

A weighed portion of the soil was added to a tared crucible and dried in an oven (100-105°C) to constant weight. The crucible was then cooled in a desiccator and reweighed. The percent moisture was calculated from the following formula:

$$\% \text{ moisture} = 100 \; \frac{\text{weight before drying} - \text{weight after drying}}{\text{weight before drying}}$$

Percent Organic Matter

The weight lost by a dry soil on heating to 550° provides a general idea of the amount of organic matter in the soil. The previously oven dried sample from the percent moisture analysis was heated in a muffle furnace at 550°C for 30 minutes. The sample was then cooled in a desiccator and reweighed. The percent organics was calculated by the following formula:

$$\% \text{ organics} = 100 \; \frac{\text{weight of dried sample} - \text{weight after ignition}}{\text{weight of dried sample}}$$

Nitrate Content

To determine nitrate content, a 2 g air dried soil sample was dispersed in 10 ml of an extracting solution containing

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 287)
TYPING GUIDE SHEET

16.66 g/l $Al_2(SO_4)_3 \cdot 18\ H_2O$

1.24 g/l H_3BO_3

4.67 g/l $AgNO_3$

2.43 g/l NH_2SO_3H

and adjusted to pH 3 with sodium hydroxide. The sample was stirred for 20 minutes and allowed to settle. The nitrate content was determined using Orion Research Meter 399A with an Orion Nitrate 93-07 electrode. The meter was calibrated with dilution of a 2000 ppm nitrate nitrogen stock solution.

Soil Microbial Populations

Each weighed sample of soil (1 g) was suspended in 10 ml of sterile distilled water to give a 1:10 dilution. Serial dilutions were prepared from this suspension. Dilutions of 1:100 through 1:100,000 were used; the appropriate dilution used being determined by the microbial count of the previous week's sample. A 0.1 ml aliquot was spread on each of 2 plates of each media for a dilutions of 1:1000 to 1:1,000,000.

The numbers of aerobic bacteria were obtained by plating on Eugonagar (Baltimore Biological Laboratories, Cockeysville, Md) and incubation at room temperature for 120 hours. The average counts of the duplicate plates were determined and corrected for one gram of soil. Yeast and mold counts were obtained by plating dilutions on Sabouraud's Dextrose Agar (Baltimore Biological Laboratories, Cockeysville, Md). Incubation was also at room temperature for 120 hours. The same method was used for reporting counts per gram of soil.

The ^{14}C activity of the soil samples was determined by an Eberline Proportional Gas Flow Counter. Windowless operation was used with P10 gas. A thin layer of soil was spread on a planchet and 5-one minute counts were taken. The net count per minute (cpm) were determined by taking the average background level plus 1.96 times the standard deviation. This value was then subtracted from the average cpm for the soil sample for net cpm. Any soil samples with net cpm of zero or less were recorded as background levels. The soil samples were then weighed in order to calculate the number of counts per gram.

The contents of the sodium hydroxide bubblers were removed several times during a test to determine if any $^{14}CO_2$ was present. Barium hydroxide was added to 10 ml of the sodium hydroxide bubbler solution to precipitate the trapped carbon dioxide as barium carbonate. The precipitate was centrifuged and a sample was dried and weighed. The ^{14}C content of the sample was determined by an Eberline Proportional Gas Flow Counter in the same manner as discussed above for the soil samples.

Organic Chemical Concentration in Soils, Carbon Filters and Condensers

Monochlorobezene--

Initially the procedure recommended by the EPA (Thompson, 1974) to remove chlorinated compounds from the soils was used. In this procedure, a known quantity of soil is placed in a Soxhlet extraction and extracted with a solvent such as methylene chloride for 1 to several hours. A florisil column is used to remove soil impurities and gas chromatography is used for quantitative analysis. The results from this procedure were compared to a simplified method. In the simplified method, 100 ml of methylene chloride were added to the weighed soil sample in the covered plastic beaker. The soil-liquid was shaken and allowed to stand for 1 hour. The samples were again shaken and an aliquot of liquid was removed and filtered through a cotton plug into GC auto sampler vials. The simplified method gave higher and more consistent results than those obtained by Soxhlet extraction. Several reasons for the better results with the simplified method versus Soxhlet extract are:

- monochlorobenzene is not adsorbed by the soil to any appreciable extent and is thus very easy to extract
- the smaller soil sample used in the Soxhlet extraction resulted in a non-representative sample
- with the smaller soil sample used in the Soxhlet, extraction, the lower concentrations were below the GC detection limits
- some monochlorobenzene was lost during the additional handling steps in with Soxhlet extraction

Because of the large number of samples, the simplified preparation method was used after the second sampling.

The extracted samples were quantified using a Varian 3700 GC with autosampler and flame ionization detector under the following conditions:

- injection port temperature: 250°C
- oven temperature: 65°C
- carrier gas: N_2 at a flow rate of 30 ml/min
- column: 1.5% OV-17, 1.95% OV-210 on Anakron Q 80/100

The peak areas were integrated with a Varian CDS 111. The results were compared to a standard curve obtained with known concentrations of monochlorobenzene in methylene chloride. Lower detection limit of the method was 1 ppm in solution.

The carbon filter and condenser contents were subjected to GC analysis by the methodology described above.

Ethion--

The Ethion was initially extracted from the soil samples in covered beakers by adding 50 ml of methylene chloride, shaking the beakers and allowing them to stand for 1 hour. The methylene chloride was then decanted and a second 50 ml of methylene chloride was added. Both washes were then combined and put into GC autosampler vials. However, it was determined that soil moisture and soil sample size of 20-40 grams resulted in recovery of the Ethion from the soils. A second procedure was then initiated to increase the percent recovery. This procedure resulted in the recovery of approximately 90% of Ethion from the soils. Duplicate 1-2 g samples were then taken from a soil sample and extracted in tubes by the following procedure:

- add 0.5 ml of methanol
- add 4.0 ml of a 50/50 methanol/methylene chloride solution - centrifuged and decant
- add 4.0 ml of methylene chloride - centrifuge and decant
- add 7.0 ml H_2O to combined organic layers
- pipet bottom layer (methylene chloride) into GC autosampler vials

The samples were quantified using a Varian 3700 GC with autosampler and flame ionization detector under the following conditions:

- injection port temperature: 290°C
- oven temperature: 218-248°C
- carrier gas: N_2 with a flow rate of 30 ml/min
- column: 1.5% OV-17, 1.95% OV-210 on Anakron Q 80/100

The peak areas were integrated with a Varian CDS 111. The results were compared to a standard curve obtained with known concentrations of Ethion in methylene chloride.

Formaldehyde--

The formaldehyde was extracted from the soil samples in the covered beakers by adding 50 ml of distilled water, shaking the beakers and allowing them to stand for 1 hour. The water was decanted from the beaker into a centrifuge tube, centrifuged at 3200 rpm for 5 minutes. The clear liquid was then put into GC autosampler vials. Recovery of formaldehyde from the soil was between 95 and 100%. The samples were quantified using a Varian 3700 GC with autosampler and flame ionization detector under the following conditions:

- injection port temperature: 290°C
- oven temperature: 135°C
- carrier gas: N_2 as a flow rate of 30 ml/min
- column: Porapak T 80/100 mesh

The peak areas were integrated with a Varian CDS 111. The results were compared to a standard curve obtained with known concentrations of formaldehyde in water.

Aniline--

Duplicate 1-2 g soil samples were taken from the soil cups, weighed and then extracted in tubes using the following procedure:

- add 0.5 ml of 20% NaOH
- add 4 ml of a 50:50 mixture methanol: methylene chloride solution, centrifuge and decant solution
- add 4 ml methylene chloride to the dirt in the tube, centrifuge and combine decant with the methanol: methylene chloride mixture
- add 7 ml water to combined organic layers - shake, centrifuge
- pipet bottom layer into sample bottles for GC analysis

The samples were quantified using a Varian 3700 GC with autosampler and flame ionization detector under the following conditions:

- injection port temperature: 300°C
- oven temperature: programmed from 140°C to 180°C at 20°C per minute
- carrier gas: N_2 with a flow rate of 30 ml/min
- columns: Carbowax 20 M with 2% KOH on Chromosorb WAW 80/100 mesh

The peak areas were integrated with a Varian CDS 111. The results were compared to a standard curve obtained with known concentrations of aniline in methylene chloride.

Chlordane--

Duplicate 1-2 g samples were weighed out from the soil sample and extracted in tubes by using the following procedure:

- add 4 ml of a 50:50 mixture of methanol:methylene chloride solution, centrifuge and decant the solution

- add 4 ml of methylene chloride to the soil in the tube, and combine with first wash

- add 5 ml water to combined organic layers

- pipet 1 ml of the bottom layer and put into 14 ml of benzene, mix and load into GC autosampler vials

The samples were quantified using a Varian 3700 GC with autosampler and flame ionization detector under the following conditions:

- injection port temperature: 300°C

- oven temperature:programmed from 170°C to 230°C at a rate of 10°C per minute

- carrier gas: N_2 with a flow rate of 30 ml/min

- column: 1.5% OV-17, 1.95% OV-210 on Anakron Q 80/100

The peak areas were integrated with a Varian CDS 111. The results were compared to a standard curve obtained with known concentrations of chlordane in methylene chloride.

Dinitrophenol--

Dinitrophenol samples were analyzed by extracting duplicate 1-2 g samples in tubes with the following procedure:

- the soil sample was air dried 30 minutes

- add 0.4 ml of 1N HCl

- soil sample dried at 60°C for 3-6 hours

- add 4 ml of a 50:50 mixture methanol/methylene chloride, centrifuge and decant

- add 4 ml of methylene chloride, centrifuge and decant and combine with first wash

- collect sample from combined organic layers for GC analysis

The dinitrophenol samples were quantified using a Varian 3700 GC with autosampler and flame ionization detector under the following conditions:

- injection port temperature: 275°C
- oven temperature: 175°C
- carrier gas: N_2 with a flow rate of 30 ml/min
- column: 1% SP-1240 DA 100/120 mesh supelcoport

The peak areas were integrated with a Varian CDS 111. The results were compared to a standard curve obtained with known concentrations of dinitrophenol in methylene chloride.

Soil and Plant Tissue Digestion and Analysis for Metals--

After collection, the soil or plant tissues were dried at 60°C for 24 hours. The plant tissues were then weighed and ground. A 0.5-2.5 g sample was then digested in a mixture of reagent grade nitric and perchloric acid for 2-4 hours. After digestion, the samples were filtered through Whatman #40 filter paper and brought up to volume with distilled water in a 25 ml volumetric flask. The samples were then analyzed on a Varian 775 Atomic Absorption Spectrophotometer at a wavelength of 283.3 nm for lead and 228.8 nm for cadmium. The absorbance units of the samples were compared to standards to determine the lead or cadmium concentrations.

SECTION 8

EXPERIMENTAL RESULTS

INTRODUCTION

The data from the four land restoration techniques are presented in this section. For each organic chemical, the soil pH, soil moisture content, soil organic content, microbial levels, and chemical levels were evaluated over time. In addition, for five of the six organic chemicals, ^{14}C radiation levels were monitored. The heavy metal vegetative uptake studies were evaluated for soil pH, soil metal levels and plant metal levels over time.

LAND RESTORATION TECHNIQUE I - MONOCHLOROBENZENE SPILL

Soil pH

The initial pH of all the soils ranged from 5.5 to 6.5. After the monochlorobenzene spill, an increase in pH of 0.5 to 1.3 units was observed. The pH values as a function of core depth over time are presented in Table B-2, B-3 and B-4 of Appendix B.

Soil Moisture Content

The percent moisture content of the soils as a function of depth are presented in Tables B-5, B-6 and B-7 of Appendix B. The days when the chambers were watered are also noted on the charts. An increase in soil moisture was observed at all levels in all chambers after the addition of the monochlorobenzene. This increase is due mainly to volatilization of the monochlorobenzene during the moisture analysis procedure. The treatments were initiated after the day 2 sampling. Both treatments-1 and 2 introduced water into the chambers. Thus, the soil moisture content of the treated chambers is higher than that of the controls.

Soil Organic Content

The percent organic content of the soils are presented in Tables B-8, B-9 and B-10 of Appendix B. The organic soils averaged around 16.3% organic content in the top layer. The sandy and clay soils had substantially less organic content. These two soils had an average organic content of 5.77 and 3.22%, respectively in the top layers. The addition of monochlorobenzene did not increase the apparent organic content. Due to the high volatility of this chemical, it would have been lost during the percent moisture analysis.

Microbial Population

The bacterial and fungal populations as a function of time for the organic, sandy-loam and clay soils are shown in Figures 26-28. The middle and bottom layer bacterial and fungal populations are presented in Figures B-1 to B-6 of Appendix B.

For the organic soils, the bacterial populations generally declined after addition of the monochlorobenzene. Fungal populations also dropped but there was a lag period of several days before the monochlorobenzene affected the more resistant fungi. The bacterial and fungal populations in the three layers showed the same die-off and recovery trends.

The bacterial populations in chambers receiving treatment-1 (T-1) began recovery within 8 days after the spill. Populations at all three layers in the T-1 chamber reached their maximum levels between day 15 and 29. In contrast the bacterial populations in the control and treatment-2 (T-2) chambers did not show significant recovery until day 15 after which rapid growth in populations was observed. The control and T-2 chambers paralleled each other in bacterial recovery reaching peak populations in all soil depths on day 29.

The behaviour of the fungal populations in the three organic chambers was more erratic than the bacterial populations. In general, a decline in the number of fungi present in the soil was observed from day 2 to day 15. The fungal population in all chambers began recovery between day 15 and 22. A second drop in fungal population in the T-1 and T-2 chambers was noted on day 29.

The addition of the monochlorobenzene to the sandy-loam soil inhibited the bacterial growth in the control and T-2 surface soil samples until day 8. The T-1 chamber had higher bacterial counts than the surface samples of the other chambers through the 22nd day. In the middle and lower soil levels, the T-1 and T-2 chambers had relatively stable populations through the 15th day. The control chambers had higher counts than the other chambers during the first 15 days. However, at day 22, the bacteria populations in the three chambers, at the middle and lower levels, were similar.

The fungal counts were erratic. However, control populations for the first 15 days after the spill were higher than the T-1 and T-2 chambers for all soil depths and throughout the test for the middle and lower levels. It can also be noted that a reduction in fungal levels occurred on the 8th day after the spill. The fungal populations generally increased on the 22nd day.

The bacterial levels in the surface clay samples initially decrease in numbers. On the 8th day, after the spill, the bacteria in the control chambers had increased more rapidly than the bacteria in chambers T-1 and T-2. The bacterial populations, at the middle clay soil depths, were reduced through the 8th day for the control chambers, and the 22nd day for the T-1 and T-2 chambers. The lower layer soil bacterial levels exhibited reduction in population levels for chambers T-1 and T-2. However, the bacterial levels in the control chamber remained relatively constant.

BEGIN FIRST LINE OF TEXT HERE
TYPING GUIDE SHEET
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD BEGIN SECTIONS HERE

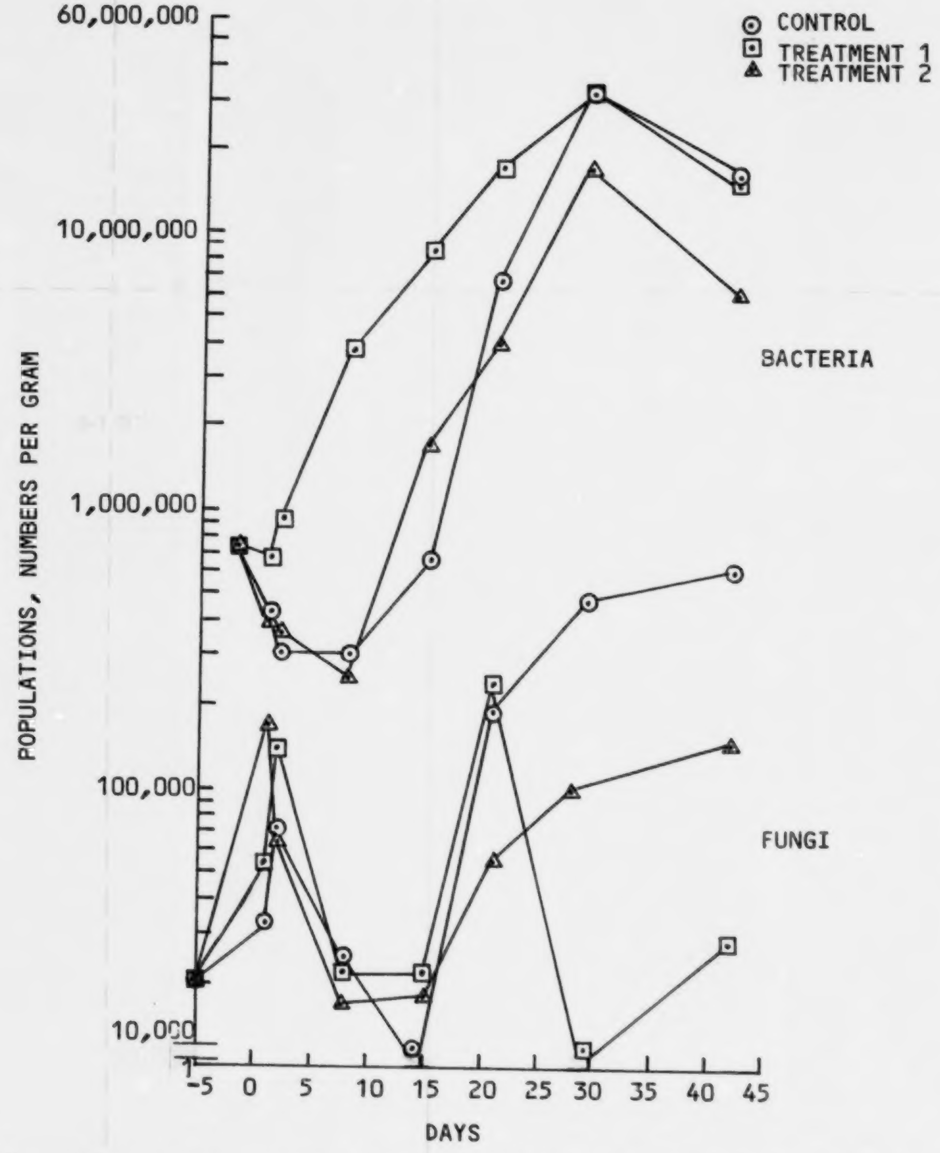


Figure 26. Upper level organic soil microbial populations - monochlorobenzene spill.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

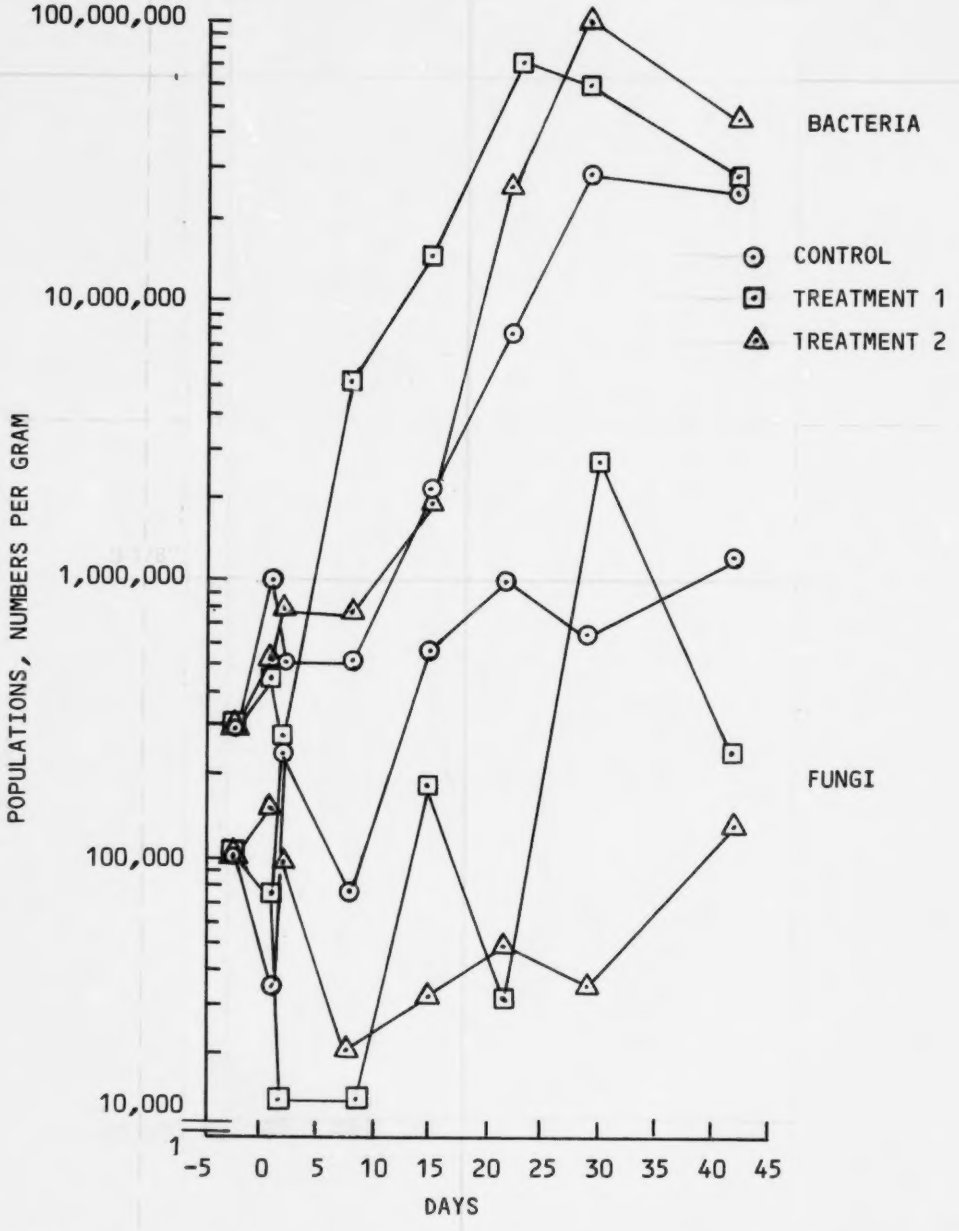


Figure 27. Upper level sandy soil microbial populations- monochlorobenzene spill.

EPA-287 (Cin.)
(4-76)

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD; BEGIN SECTIONS HERE

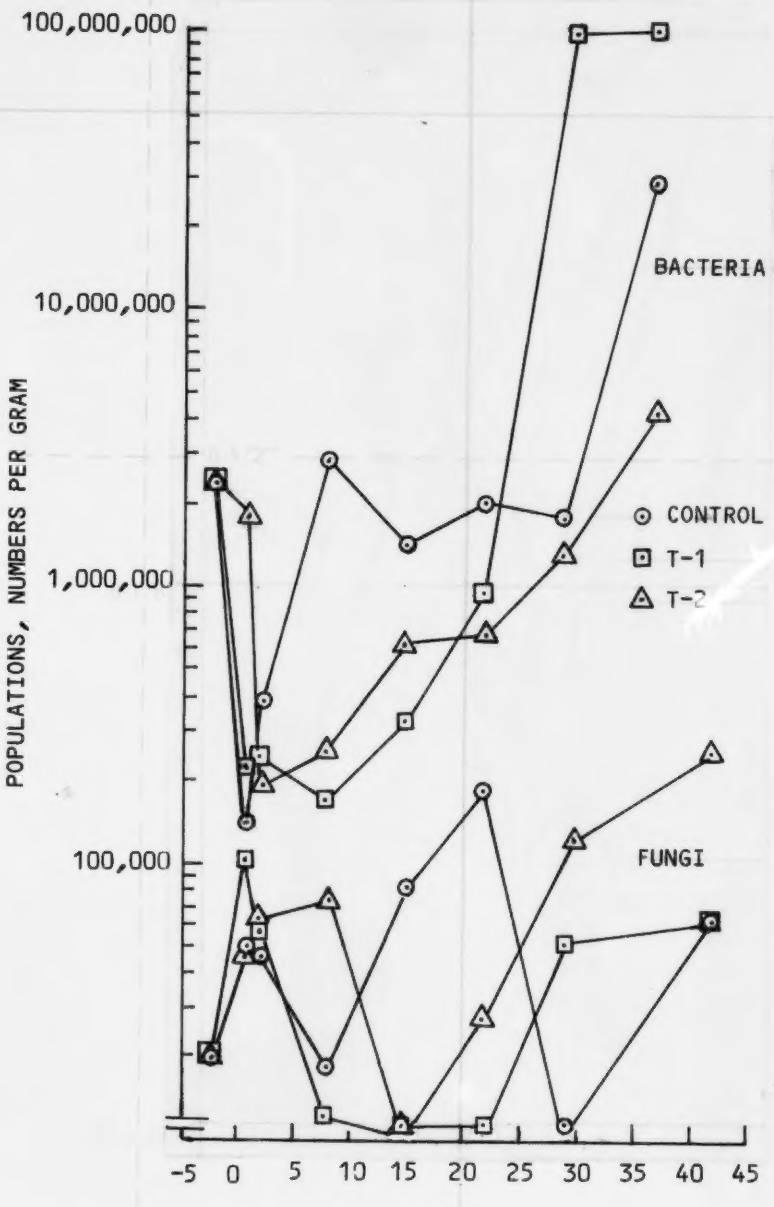


Figure 28. Upper level clay soil microbial populations - monochlorobenzene spill.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

The erratic fungal populations observed in the clay soils make any interpretation difficult. No definite toxic effects were observed on the fungi in the clay soils.

Soil Monochlorobenzene Levels

The monochlorobenzene levels as a function of soil types and soil depths are plotted versus time in Figures 29-31. The monochlorobenzene was essentially removed from the organic soils after the 8th day. The sandy-loam soils monochlorobenzene levels were low after 15 days and the clay soils monochlorobenzene levels were zero after 22 days.

In the organic soil the monochlorobenzene levels in the T-1 chamber were rapidly reduced to low levels. The control and T-2 chambers retain the monochlorobenzene somewhat longer, but after the 8th day, the monochlorobenzene levels in the soils were similar.

The sandy-loam soil did not lose the monochlorobenzene as rapidly as the organic soil. The control chamber had no monochlorobenzene present after the 8th day. However, the T-2 chamber had monochlorobenzene present until the 22nd day and in chamber T-1, monochlorobenzene was found through the 15th day in the top two depths and the 22nd day at the lower depth.

The monochlorobenzene loss as a function of time measured for clay was similar to the results obtained for sandy-loam soil. The monochlorobenzene was lost from the control chamber by the 8th day. Chambers T-1 and T-2 had monochlorobenzene until the 22nd day.

Discussion

Monochlorobenzene was somewhat toxic to soil bacteria and was highly toxic the grass. Within 1-2 hours after the spill, the grass was wilted. Twenty four hours later, it had completely turned brown. Monochlorobenzene was rapidly lost from the soil as evidenced by the high concentration of monochlorobenzene found in the carbon filters and traps. The loss of monochlorobenzene by evaporation from the treated chambers was retarded due to the addition of 2 liters of nutrient broth during treatment. The addition of liquid tended to push the monochlorobenzene deeper into the soil and hold it there longer.

No evidence of microbial degradation of monochlorobenzene was observed during the tests. No additional compounds were seen in the GC traces, and no $^{14}CO_2$ was found in the sodium hydroxide bubblers. However, the monochlorobenzene soil levels correlated well to the bacterial levels. The bacterial populations were depressed when significant monochlorobenzene concentrations were in the soil. As soon as the monochlorobenzene had evaporated from the soil, the bacterial populations recovered.

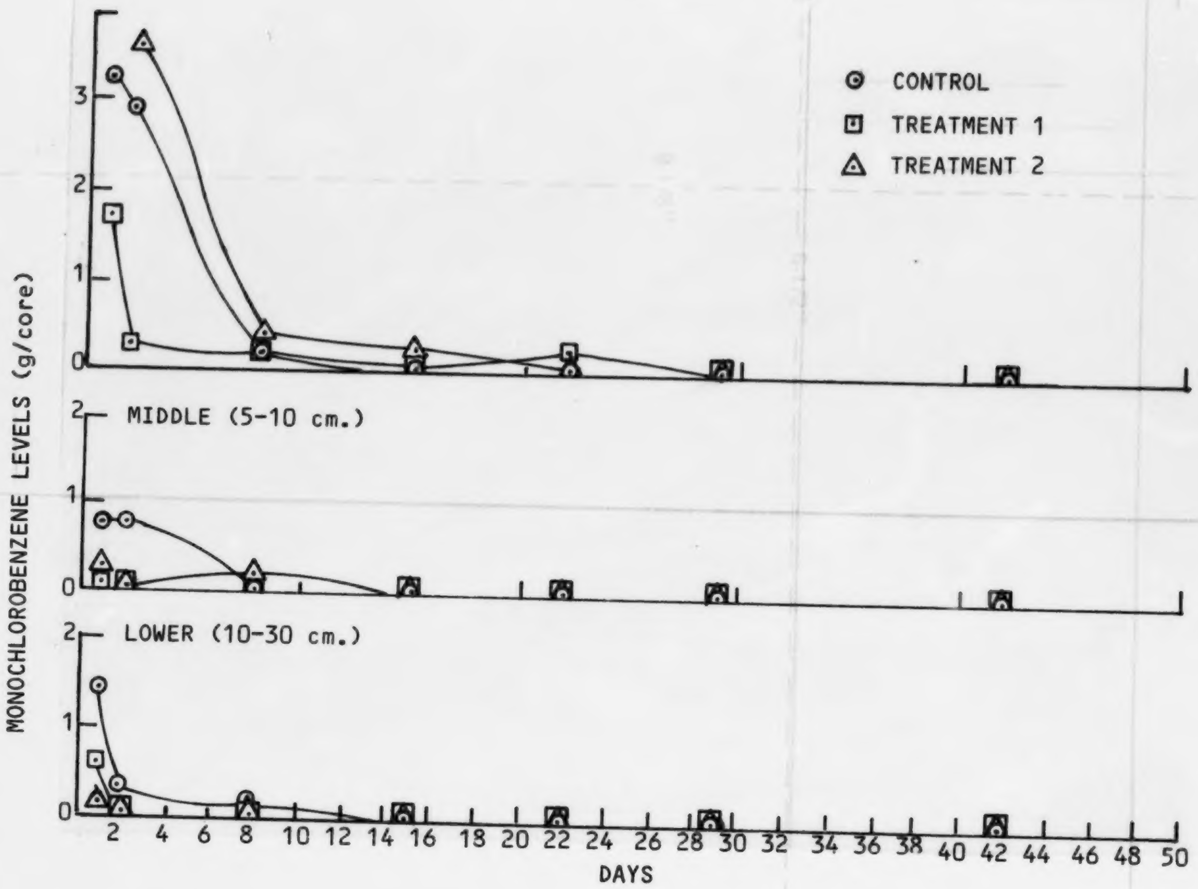


Figure 29. Monochlorobenzene concentrations in the organic soils.

EPA-287 (Cin.)
(4-76)

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
DROPPED HEAD; BEGIN SECTIONS HERE
CENTER OF PAGE
TOP OF IMAGE AREA
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

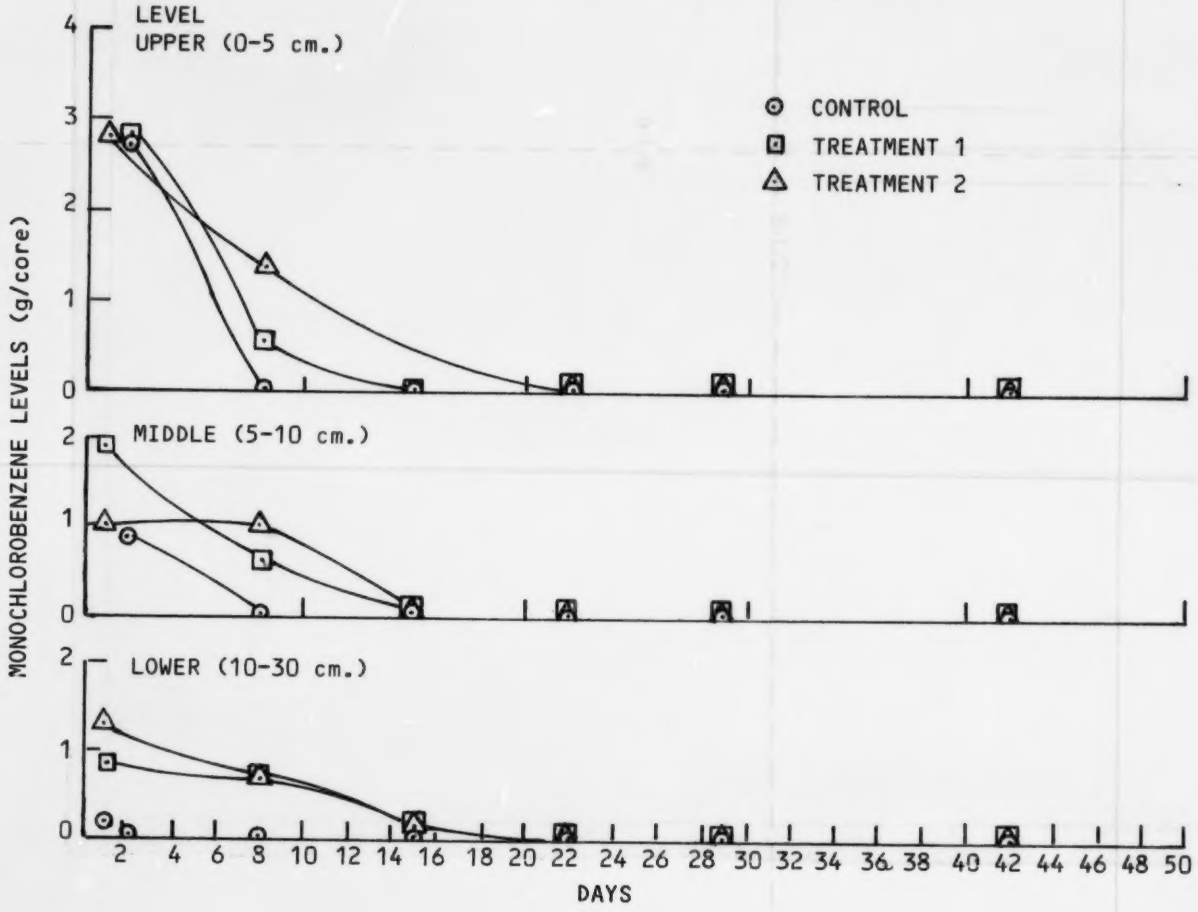


Figure 30. Monochlorobenzene concentrations in the sandy soils.

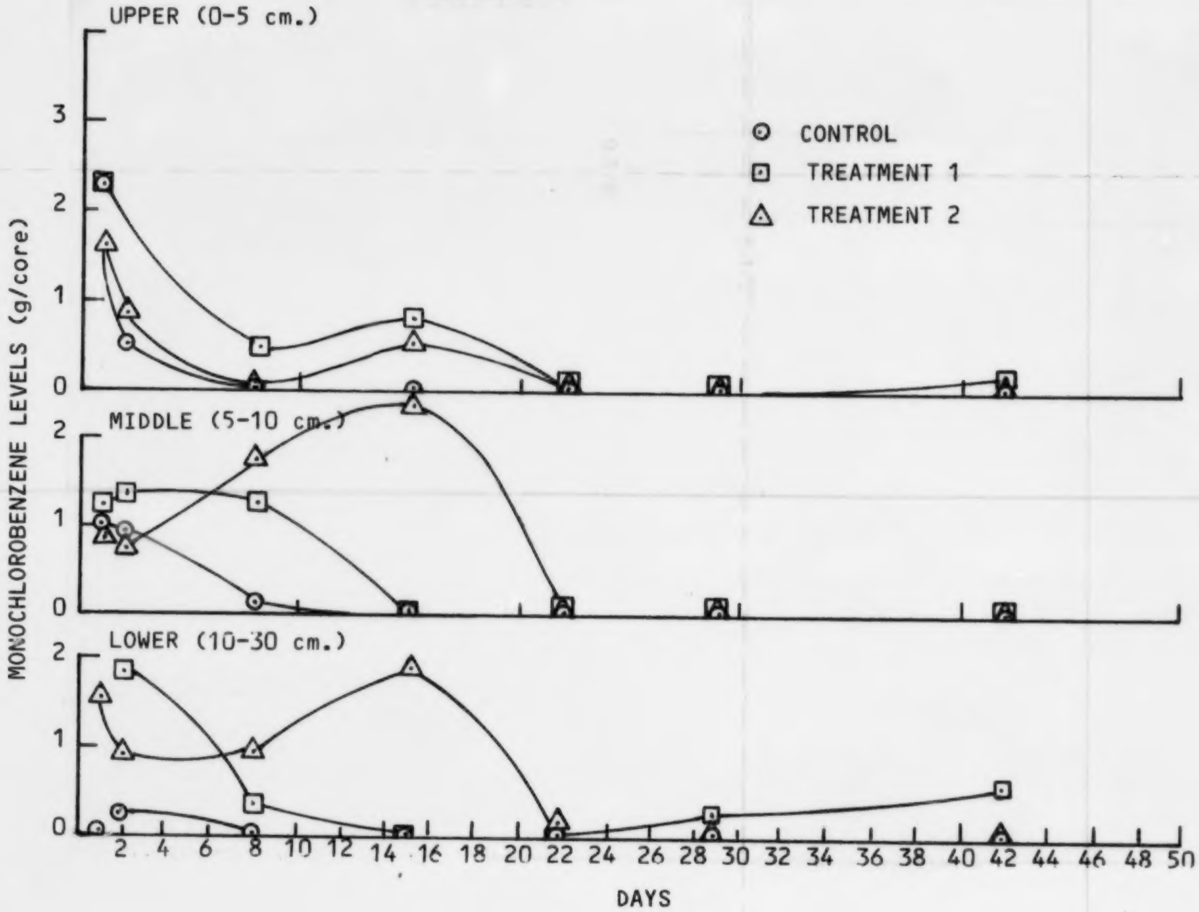


Figure 31. Monochlorobenzene concentrations in the clay soils.

The simulated spill of monochlorobenzene was a good example of the movement of a volatile, low polarity, low water solubility compound in soils. The monochlorobenzene evaporated from the soils tested within 28 days after the spills. The treatment methods applied to the soils were relatively ineffective because they involved wetting the soil surface. The wet soil reduced the evaporation rate of the monochlorobenzene in the treated chambers. The control chambers, which did not receive any water after the spill, had uninhibited evaporation of the monochlorobenzene from the soil and recovery of normal soil fauna.

LAND RESTORATION TECHNIQUE I - ETHION SPILL

Soil pH

The pH values of the organic, sandy-loam and clay soils as a function of soil depth and time are compiled in Tables C-2, C-3 and C-4 of Appendix C. The initial pH levels of the organic soils were near neutral. However, after the Ethion spill, the soil pH values dropped to the 5-6 range. The pH levels in the control chamber remained in the 4.7 to 5.4 region throughout the remainder of the test. The soil in the treated chambers was limed on days 48 and 55. The lime increased the pH to near neutral levels. However, by day 94, the pH had again decreased to between 5 and 6 units. The treated chambers received the ethanol-NaOH treatments after day 200. Soil pH levels after treatment ranged from 9.6-12.5.

Sandy soil pH levels were also initially near neutral. For the first nine weeks after the Ethion spill, the soil pH values ranged from 3.3-6.0. The soil pH in the control chambers after the spill ranged between 4.0-5.4 units for the remainder of the study. The treated chambers were limed days 48 and 55 raising the pH values to between 6.0 and 7.3. Over the next 60 days, the sandy soil pH values decreased by one or two pH units. The ethanol-NaOH solutions were applied to the treated chambers after day 200 raising the pH values to between 10.0-11.4.

Initial pH levels of the clay soils were 6.4. After the Ethion spill, soil pH levels ranged from 3.7-4.5. The pH levels in the control chamber ranged from 3.2-5.9 for the remainder of the study. The treated soil chambers were limed on days 48 and 55. The lime raised the pH of the clay soils to near 6.0 units. After day 200, ethanol and NaOH solutions were applied to the treated soil chambers. The soil pH levels were raised to levels from 10.0-10.9.

Soil Moisture Content

The percent moisture levels as a function of soil type, depth and time are compiled in Tables C-5, C-6 and C-7 of Appendix C. The moisture content in the upper layer of the control organic chamber ranged between 6.6-35.8% and averaged near 18%. The T-1 organic chamber had moisture levels in the upper layer of soil ranging from 10.0-42.1% and averaged near 22%. The T-2 organic chamber had moisture values in the upper layer of soil ranging from 12.0-36.5% and averaged near 25%.

The moisture levels in the upper sandy soil layer in the control chamber ranged from 7.3-38.4% with an average of 16%. The T-1 sandy soil chamber had moisture levels in the upper soil layer ranging from 8.8-25% with an average of 20%. The T-2 chamber had percent moisture values in the upper soil layer ranging from 5.6-32.3% with an average of 18%.

The moisture levels in the clay control chambers upper layer, ranged between 5.9-24.3% with an average of 14%. The T-1 chamber had percent moisture levels in the upper soil layer, ranging between 3.7-21.3, with an average of 12.3%. The T-2 chamber had moisture values in the upper soil layer ranging from 3.2-25.4%, with an average of 15.4%.

Microbial Populations

The bacterial populations in the organic soil, top layer are presented in Figure 32. Bacterial populations dropped substantially in the first two days after the spill. The treated soil bacterial levels recovered quickly due to the nutrients added to the soil. The treated soils had bacterial levels 6-40 times greater than the control chambers.

Over the next four months, the bacterial populations remained fairly constant in all the organic soil chambers. However, when ethanol and NaOH treatments were applied to the soil in the T-2 chamber, the population was lowered by 2-3 orders of magnitude.

Fungal populations in the upper organic soil layer are presented in Table 48. After the spill,the fungal levels decreased slightly in all the organic soil chambers. However, by day 9 the fungal populations had increased substantially. Fungal populations remained fairly stable through day 183. Small areas of the T-1 chamber were treated with ethanol-NaOH solutions on day 185. As a result the fungal populations were reduced to low levels. The entire T-2 organic soil chamber was treated with ethanol-NaOH solutions on day 210 and as a result the fungal population was reduced to less than 1000 organisms/g for the remainder of the experiment.

The bacterial levels in the middle and lower organic soil layers are presented in Figures C-1 and C-2 of Appendix C. The microbial levels in the middle layers were reduced slightly in the first two days after the spill. The microbial populations then recovered in the next two weeks and remained stable for four months. The control soil chamber microbial population in the middle soil layer recovered as rapidly as the treated soil chambers. Bacterial levels in the lower layer of the organic soil were reduced by about 4 times after the spill and recovered rapidly. Also after the treatment with the ethanol and NaOH solutions, the levels did not fall off as much as the top and middle layers.

The bacterial levels in the top layer of the sandy soil are presented in Figure 33. They decreased from 1/3 to 1/7 of the original levels in the first two days after the Ethion spill. The populations then recovered over the next 2-3 weeks. The bacteria in the T-2 chamber had levels 10 times greater than the other chambers. Over the next four months, the bacterial levels in the treated chambers were typically greater than the control chamber. The higher bacterial populations in the treated soil were probably due to the nutrients that were added. Once again, when the ethanol and NaOH solutions were applied, the population decreased by 2-3 orders of magnitude.

A. T-1 AND T-2, NUTRIENT BROTH, T-2 PLOWED
B. T-1 AND T-2, LIMED, T-2 PLOWED
C. T-1 AND T-2, LIMED AND NUTRIENT BROTH
D. T-1 AND T-2, NUTRIENT BROTH AND TWEEN 80
E. T-1 AND T-2, ETHANOL-WATER SOLUTION
F. T-2, ETHANOL-NaOH SOLUTION

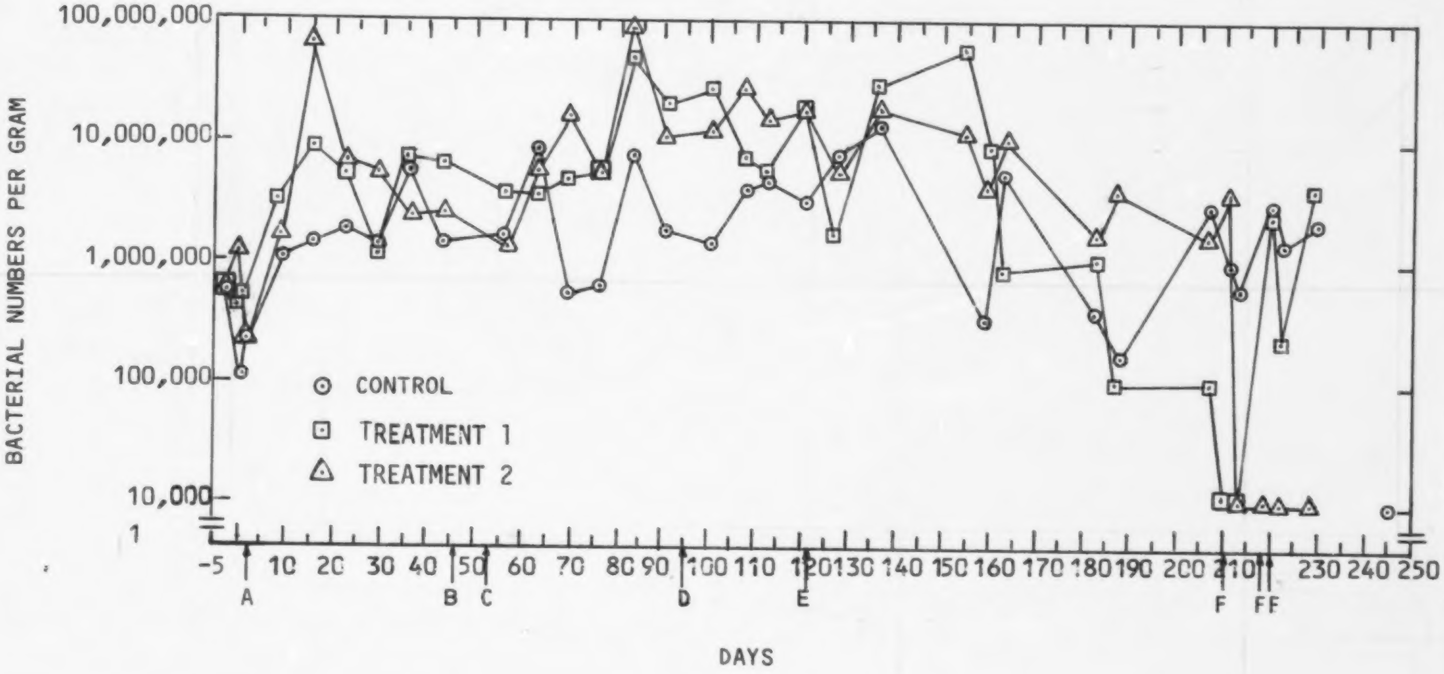


Figure 32. Upper level organic soil bacterial populations - Ethion spill.

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
DROPPED HEAD: BEGIN SECTIONS HERE
CENTER OF PAGE
TOP OF IMAGE AREA
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TABLE 48. UPPER LAYER FUNGAL COUNTS ($X10^4$/gram of soil) - ETHION SPILL

	DAY										
Soil Type and Treatment	Initial	1	2	9	16	23	30	37	44	52	59
Organic Soil Control	5.6	-	4.6	188.0	175.0	75.0	33.0	267.0	117.0	28.8	86.7
T-1	5.6	2.7	2.9	275.0	57.0	33.0	10.8	58.8	17.0	89.0	48.0
T-2	5.6	-	9.8	73.0	270.0	-	38.0	12.3	32.4	20.0	12.9
Sandy Soil Control	66.7	2.2	3.6	-	173.0	50.0	52.0	70.0	141.3	80.0	77.5
T-1	66.7	5.2	1.9	80.0	267.0	140.0	140.0	180.0	175.0	46.4	62.5
T-2	66.7	5.7	7.1	385.0	650.0	87.0	50.0	617.0	725.0	54.3	29.2
Clay Soil Control	22.0	3.3	16.7	110.0	81.0	43.0	70.0	14.0	18.0	115.0	21.0
T-1	22.0	5.0	5.0	78.0	88.0	125.0	115.0	40.0	20.6	85.7	13.1
T-2	22.0	5.4	7.5	330.0	363.0	33.0	350.0	20.0	13.0	47.5	47.9

(continued)

TABLE 48 (continued)

Soil Type and Treatment	DAY 65	72	79	86	101	108	113	121	127	136	155
Organic Soil Control	40.7	27.5	310.0	113.0	86.3	78.8	116.0	180.0	129.0	290.0	242.0
T-1	60.0	63.8	150.0	106.0	163.0	52.0	66.7	172.2	7.7	56.5	615.0
T-2	25.5	26.2	100.0	17.3	23.0	25.0	17.0	38.8	22.5	355.0	378.0
Sandy Soil Control	86.1	55.0	10.0	150.0	275.0	110.0	11.0	258.0	103.0	482.0	1420.0
T-1	129.0	317.0	250.0	400.0	333.0	157.0	167.0	192.0	57.0	2462.0	1340.0
T-2	89.4	67.3	80.0	66.7	82.5	180.0	98.8	81.9	24.5	88.5	1250.0
Clay Soil Control	73.1	46.2	62.8	118.0	20.0	70.0	100.0	78.0	25.0	91.0	102.0
T-1	29.4	70.0	22.4	128.0	263.0	83.0	129.0	-	72.0	393.0	178.0
T-2	36.7	53.8	95.0	77.5	85.0	55.7	131.4	36.0	-	530.0	1310.0

(continued)

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
DROPPED HEAD, BEGIN SECTIONS HERE
CENTER OF PAGE
TOP OF IMAGE AREA
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
DROPPED HEAD; BEGIN SECTIONS HERE
CENTER OF PAGE
TOP OF IMAGE AREA

TABLE 48 (continued)

Soil Type and Treatment	DAY 159	163	183	187	205	212	220	222	228	238	256
Organic Soil Control	22.73	57.9	32.5	23.5	66.9	18.0	129.6	40.9	50.0	26.3	41.8
T-1	14.30	26.1	75.9	.97	1.1	0.8	0.68	3.67	0.24	-	1.75
T-2	8.96	338.3	60.3	17.97	97.9	2.0	-	-	0.0045	0.053	0.0045
Sandy Soil Control	3.7	191.4	68.9	29.4	131.1	240.0	-	86.4	1.2	142.6	44.7
T-1	235.8	254.0	1175.0	.68	40	7.0	0.076	1.43	1.8	-	0.13
T-2	6.12	2826.0	393.0	298.0	208.0	-	20.0	-	0.015	-	0.032
Clay Soil Control	3.01	43.8	74.0	235.0	3.02	tntc	9.18	-	-	2.34	11.7
T-1	0.67	4.73	12.8	.026	0.43	0.13	0.385	1.31	0.467	0.972	0.473
T-2	55.7	1799.0	160.0	36.0	208.0	-	-	-	0.068	-	0.017

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA. OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

A. T-1 AND T-2, NUTRIENT BROTH, T-2 PLOWED
B. T-1 AND T-2, LIMED, T-2 PLOWED
C. T-1 AND T-2, LIMED AND NUTRIENT BROTH
D. T-1 AND T-2, NUTRIENT BROTH AND TWEEN 80
E. T-1 AND T-2, ETHANOL-WATER SOLUTION
F. T-2, ETHANOL-NaOH SOLUTION

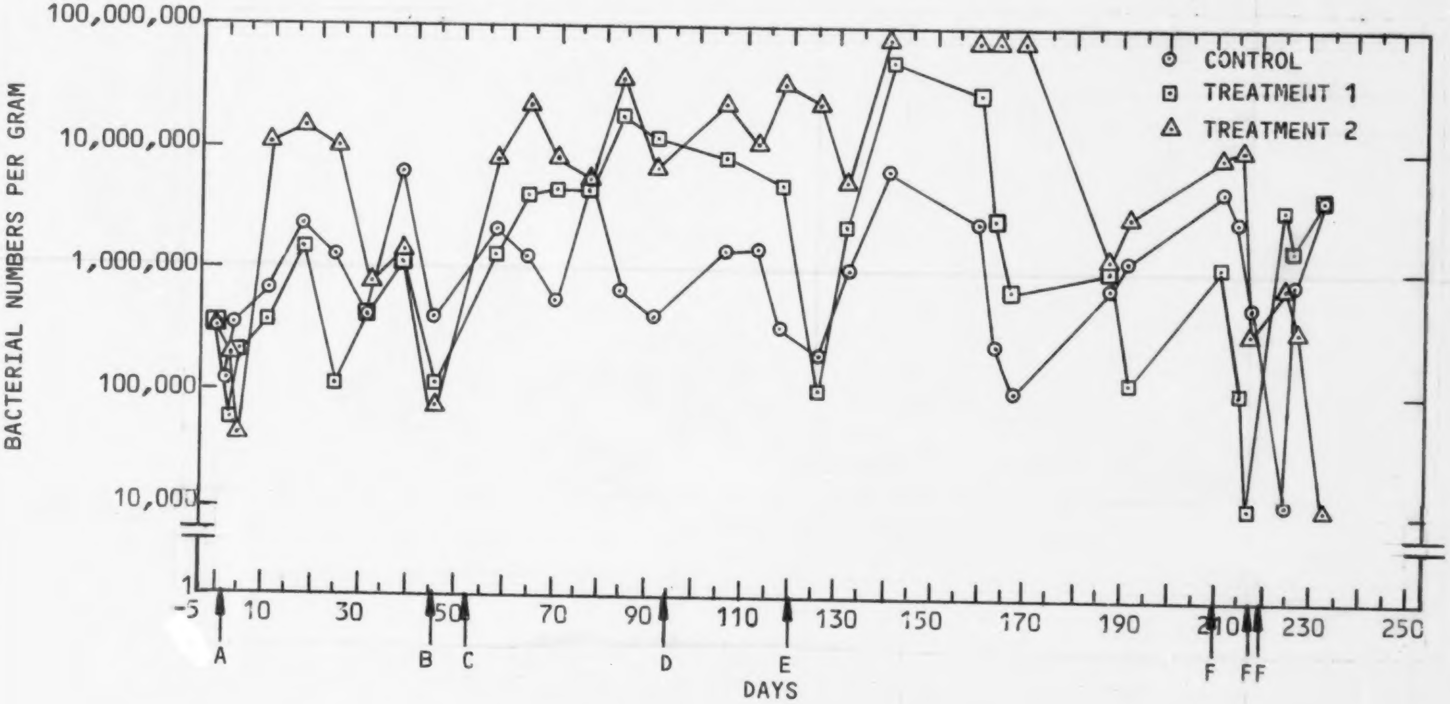


Figure 33. Upper level sandy soil bacterial populations - Ethion spill.

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
DROPPED HEAD. BEGIN SECTIONS HERE
CENTER OF PAGE
TOP OF IMAGE AREA
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

The upper sandy soil layer fungal populations are presented in Table 48. The fungal population in the top sandy soil layer decreased to about 1/10 of their original levels in the first two days after the spill. The fungal population recovered over the next two to three weeks. During the next four months, the fungal populations remained fairly stable, with no differences between the control and treated chambers. When the ethanol and NaOH solutions were applied to the soil, the populations in the treated soils were reduced by two orders of magnitude.

The bacterial levels in the middle and lower sandy soil layers are presented in Figures C-3 and C-4 of Appendix C. In the middle soil layer, the microbial levels decreased 1/3 to 1/2 their initial values in the first two days after the spill. During the next four months, the populations were relatively constant. When the ethanol and NaOH solutions were added to the T-2 chamber, the population decreased by 2-3 orders of magnitude.

After the Ethion spill, the bacterial levels in the lower sandy layers decreased to 1/2 to 1/5 of their original values. Microbial levels remained relatively steady over the next four months. When the ethanol and NaOH solutions were added to the soil in the T-2 chamber, bacterial levels decreased by about 1/2. Fungal levels in the T-2 chamber were not different from the populations in the control and T-1 chamber.

The bacterial populations in the top level of the clay soils are presented in Figure 34. The populations decreased to 1/4 to 1/25 times their original values after the Ethion was spilled on the soil. During the next 2-3 weeks, the bacterial populations recovered. The populations in the T-1 and T-2 chambers were significantly higher than the control chamber over the next four months. The treatments of nutrient broth and pH adjustment were probably responsible for the greater bacterial populations in the treated chambers. Once again, when the ethanol and NaOH solutions were added, the bacterial populations in the treated chambers decreased by 2-3 orders of magnitude. Fungal populations in the upper clay soil layer are presented in Table 48. Fungal populations decreased to 1/4 to 1/2 of their original levels in the first two days after the spill. The populations recovered by the 16th day and remained relatively stable for the next four months. When ethanol and NaOH solutions were added to the treated chambers the fungal populations decreased by 2-4 orders of magnitude.

The clay soil middle and lower layer bacterial populations are presented in Figures C-5 and C-6 of Appendix C. Middle layer bacterial levels decreased to 1/2 to 1/4 of the original levels in the first two days after the Ethion spill. Fungal levels, however, were not consistant in their response to the Ethion spill. Both bacterial and fungal levels remained relatively constant over the next four months. When the treated chambers received the ethanol and NaOH solutions, the levels dipped by 2-3 orders of magnitude. The microbial levels in the lower clay soil layer decreased to 1/3 of their original values after the Ethion was spilled on the soil. The populations remained fairly stable over the next four months. When the ethanol and NaOH solutions were applied to the treated chambers, the microbial levels decreased by about 2 orders of magnitude.

A. T-1 AND T-2, NUTRIENT BROTH, T-2 PLOWED
B. T-1 AND T-2, LIMED, T-2 PLOWED
C. T-1 AND T-2, LIMED AND NUTRIENT BROTH
D. T-1 AND T-2, NUTRIENT BROTH AND TWEEN 80
E. T-1 AND T-2, ETHANOL-WATER SOLUTION
F. T-2, ETHANOL-NaOH SOLUTION

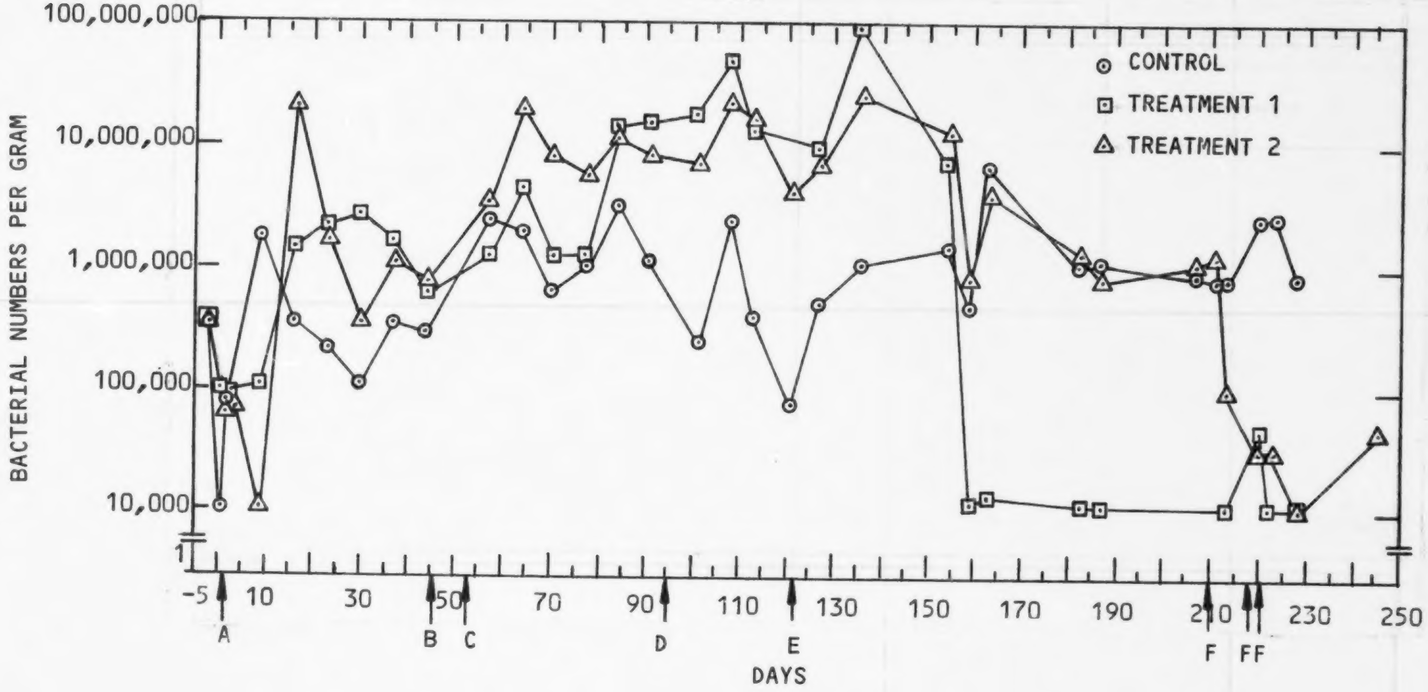


Figure 34. Upper level clay soil bacterial populations - Ethion spill.

Soil Ethion Levels

The Ethion levels in the top layers of the organic, sandy and clay soils as a function of time after the spill are shown in Figures 35-37. The erratic Ethion concentrations in the soils were due primarily to variation in soil moisture levels which influenced the percentage recovery. The apparent increase in the Ethion levels after day 155 was the result of improved extraction procedures. The extraction procedure which was used after day 155 is detailed in the Analytical procedures part of Section 7.

Discussion of Results

In contrast to monochlorobenzene, Ethion did not have an immediate effect on the grass. The grass in all chambers remained healthy for about 1 month after the spill. The vegetation then slowly wilted and turned brown. During the first five months after the spill, the Ethion levels in the soils gradually decreased. The initial treatments, with nutrients or nutrients with aeration, on day 3, were not effective in significantly increasing the degradation rate of Ethion by indigenous microorganisms. Adjustment of soil pH on day 44, day 46 and day 53 also did not improve the Ethion degradation rate.

The microbial populations were sufficiently high in the treated chambers. It appeared the microbes were capable of living in the presence of Ethion. However, either the organisms were incapable of degrading the Ethion or the Ethion was unavailable to the organisms. Two methods were tried to improve the water solubility of Ethion and thus its availability to the microbial populations, i.e., the addition of a surfactant (Tween 80) and the addition of ethanol. These treatments were applied to the T-1 and T-2 chambers on day 95 and day 122, respectively. These treatments did not improve the Ethion degradation rate by microorganisms.

Iwata et al. (1975) found Ethion to be a persistent organophosphorus pesticide. In their studies, only 28% of the Ethion was removed from the soil in a 200 day period. They calculated the half-life of Ethion in soils to be 420 days. Our data show that 51% of Ethion was removed from the organic soil in 162 days. The percent Ethion removed from the sandy and clay soils over the same period were 43 and 60%, respectively. The half-lives of Ethion assuming a first order decay in the three soil types were calculated to be:

- 157 days - organic
- 200 days - sandy
- 123 days - clay

On day 210, day 219 and day 220, the T-2 chambers were treated with a total of 10 liters each of a 50:50 ethanol-water solution containing 6.8% sodium hydroxide. The purpose of this treatment was to determine if the Ethion could be hydrolyzed in the soil. The pH of the top layer of soil was raised to 10-12 by this treatment. Due to the high pH, microbial levels dropped drastically. In the organic soil, the hydrolysis treatment reduced the Ethion levels from 55,000 ppm to less than 4,000 ppm. Ethion levels in the top layer of the sandy soil decreased from approximately 60,000 ppm to less than 10,000 ppm. The Ethion levels in the clay soil were not substantially affected by the treatment.

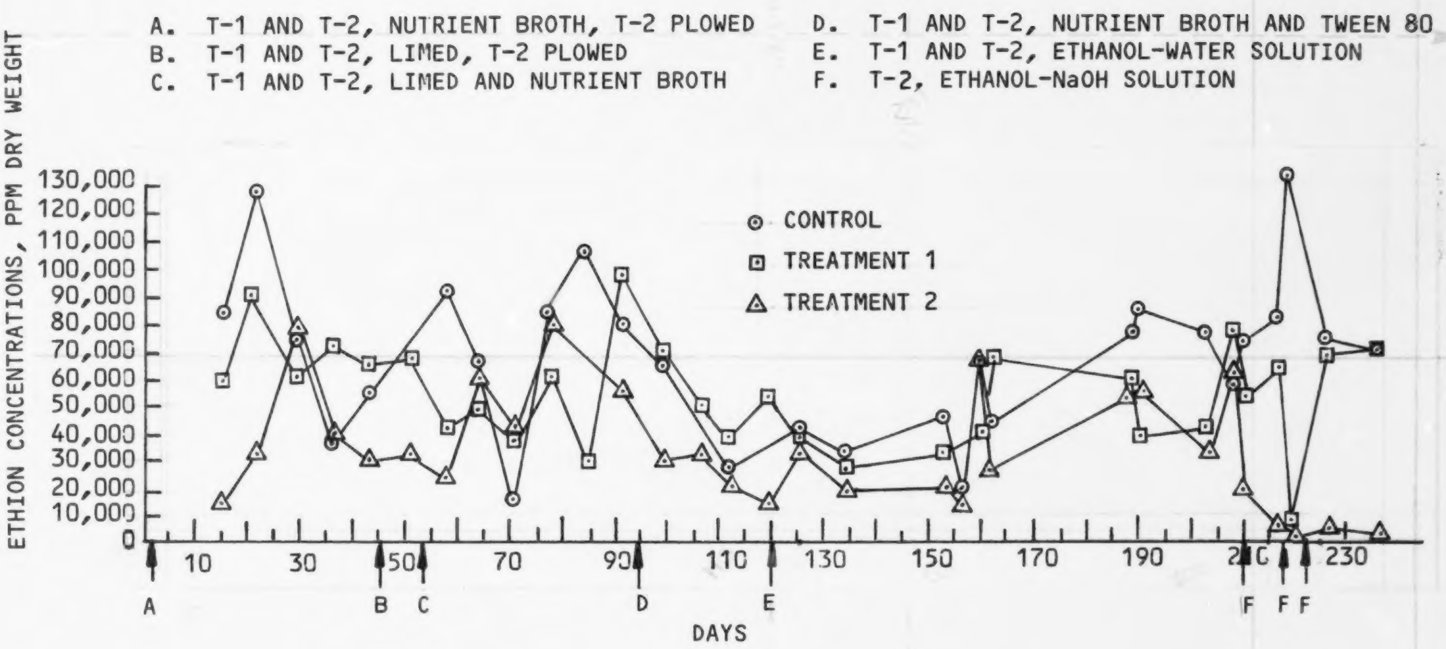


Figure 35. Upper level ethion concentrations in organic soil.

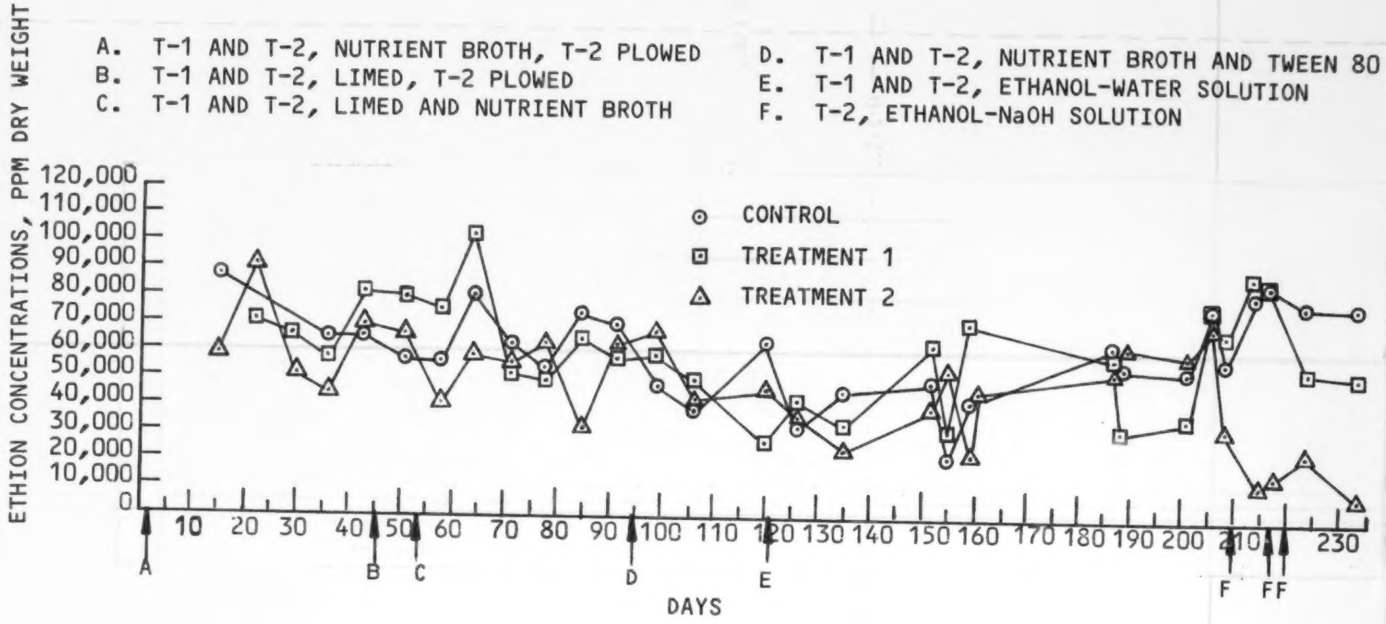

A. T-1 AND T-2, NUTRIENT BROTH, T-2 PLOWED
B. T-1 AND T-2, LIMED, T-2 PLOWED
C. T-1 AND T-2, LIMED AND NUTRIENT BROTH
D. T-1 AND T-2, NUTRIENT BROTH AND TWEEN 80
E. T-1 AND T-2, ETHANOL-WATER SOLUTION
F. T-2, ETHANOL-NaOH SOLUTION

Figure 36. Upper level ethion concentrations in sandy soil.

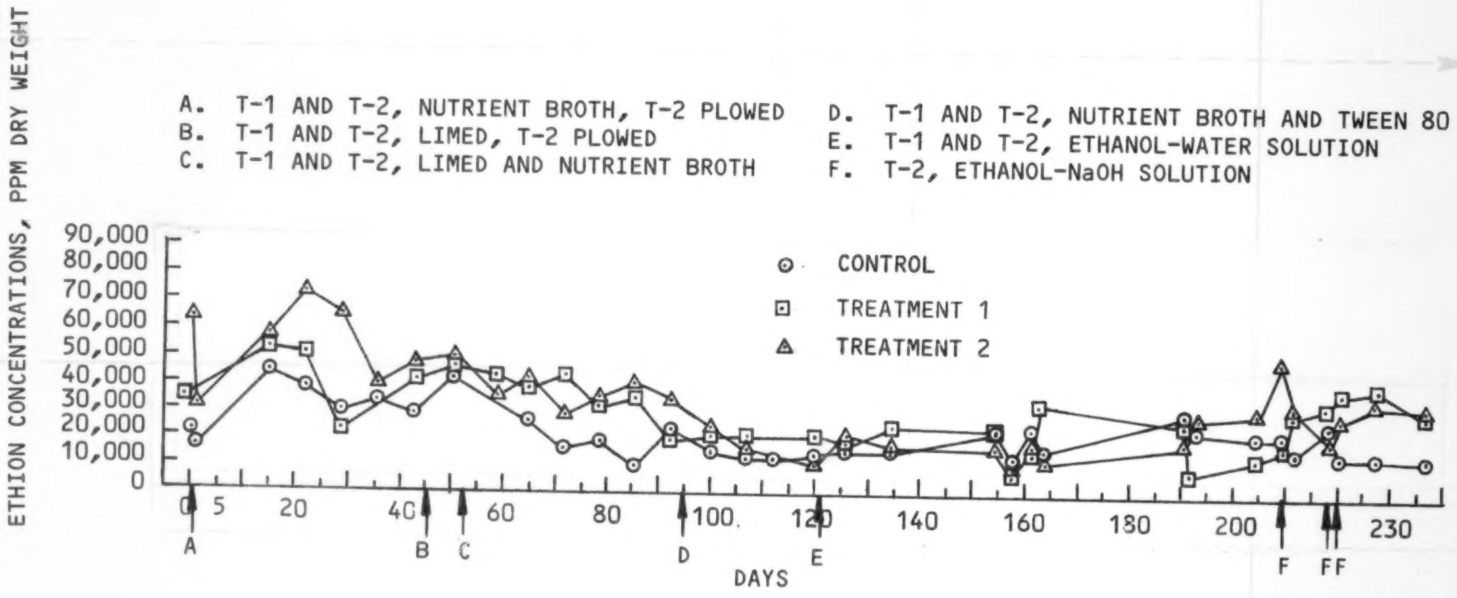
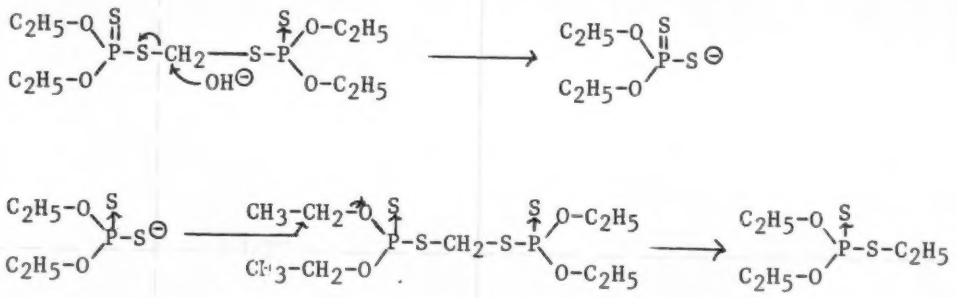


Figure 37. Upper level ethion concentrations in clay soil.

Following treatment with sodium hydroxide and ethanol, a number of tentative degradation products were observed by gas chromatography/mass spectroscopy. None of the observed peaks could be matched to entries in the NIH/EPA Mass Spectral Search System (MSSS). Tentative molecular formulae and possible structural assignments for several the peaks are presented in Table 49. However, confirmation of identity without isolation of sufficient material for NMR and IR spectra is not possible. The tentative structures are consistant with products which might be expected from multiple nucleophilic displacements. For example, the most abundant product "B" could be formed by the following route:



Radiation Levels

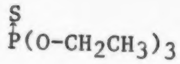
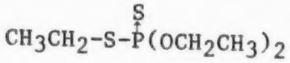
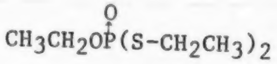
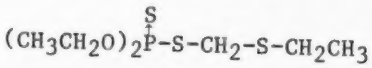
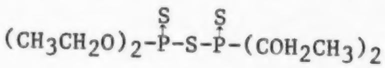
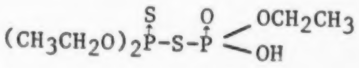
The ^{14}C radiation levels in the top layers of the organic, sandy and clay soils are compiled in Figures C-7, C-8 and C-9 of Appendix C. The radiation levels in all soils were variable but indicate a loss of activity over time. After the ethanol-NaOH solution treatment, the radiation levels in the T-2 chambers did not decrease significantly. These results indicated that the S-CH_2-S-carbon in the center of the Ethion molecule (the ^{14}C labelled site) was still present in the soil.

Regression lines, by the least squares method, were fit to the net ^{14}C levels in the soils to give a percentage lost over time. A first order decay was used to give the following half-life estimates for Ethion:

- 162 days - Organic soil
- 117 days - Sandy soil
- 159 days - Clay soil

The time period was for days 65 to 220, or over a 155 day period. Except for the sandy soil, the radiation half-lives agree fairly well with the half-lives determined from Ethion levels.

TABLE 49. ETHION RELATED RESIDUES

Peak	Molecular Ion	Base	Suggested Formulae	Possible Structure
A	198	121	$C_6H_{15}PO_3S$	 $\overset{\overset{S}{\uparrow}}{P}(O\text{-}CH_2CH_3)_3$
B	214	186	$C_6H_{15}PO_2S_2$	 $CH_3CH_2\text{-}S\text{-}\overset{\overset{S}{\uparrow}}{P}(OCH_2CH_3)_2$
C	214	125	$C_6H_{15}PO_2S_2$	 $CH_3CH_2O\overset{\overset{O}{\uparrow}}{P}(S\text{-}CH_2CH_3)_2$
D	260	121	$C_7H_{17}PO_2S_3$	 $(CH_3CH_2O)_2\overset{\overset{S}{\uparrow}}{P}\text{-}S\text{-}CH_2\text{-}S\text{-}CH_2CH_3$
E	338	245	$C_8H_{20}P_2O_4S_3$	 $(CH_3CH_2O)_2\text{-}\overset{\overset{S}{\uparrow}}{P}\text{-}S\text{-}\overset{\overset{S}{\uparrow}}{P}\text{-}(COH_2CH_3)_2$
F	296	81	$C_6H_{15}P_2O_5S_2$	 $(CH_3CH_2O)_2\overset{\overset{S}{\uparrow}}{P}\text{-}S\text{-}\overset{\overset{O}{\uparrow}}{P}\begin{matrix}OCH_2CH_3\\OH\end{matrix}$
G	384	231	$C_9H_{22}P_2O_4S_4$	Ethion

LAND RESTORATION TECHNIQUE II - FORMALDEHYDE SPILL

Soil pH

The soil pH values as a function of core depth over the test period for the organic, sandy and clay environmental chambers are presented in Tables D-2, D-3 and D-4 of Appendix D. The organic soil was initially neutral in pH. The first four days after the spill, the upper layer of the soil was basic. However, the soil then became acidic, leveling off at a pH in the 5.3-6.2 range. On days 52 and 64, lime was added to the treatment-1 and -2 chambers to raise the pH. The top soil layers of these chambers reached a pH of 6.3-6.4.

The sandy soil was initially slightly acidic. Through the first four days after the spill, the soil was slightly basic. The pH leveled off at a pH range from 4.3-5.8. Lime was added to the treatment-1 and -2 chambers on days 52 and 64 raising the pH in the top layer of soil to 6.0.

The clay soil initially had an acidic pH. The first two days, after the spill, the pH levels increased to a neutral pH. The pH then decreased to a range from 4.4-5.9. Lime was added to the treatment-1 and -2 chambers on days 52 and 64 raising the pH in the top layer of soil to 5.1-5.5.

Soil Moisture Content

The percent moisture data of the soils are presented in Tables D-5, D-6 and D-7 of Appendix D. The organic soils had the highest moisture levels, typically in the 20-30% range. The sandy and clay soils were slightly drier with a typical moisture range from 15-25%. Throughout the experiment, the moisture levels remained relatively stable and did not substantially alter the microbial levels in the soil.

Microbial Populations

The bacterial populations in the top layers of the organic, sandy and clay soils are presented in Figures 38-40. Middle and lower soil layer microbial populations are presented in Figures D-7 to D-12 of Appendix D.

The bacterial count in organic soil was reduced 2 to 3 orders of magnitude after the addition of formaldehyde. By day 56, the bacterial levels in the top soil layer had recovered. Fungal populations in the upper organic soil layer are presented in Table 50. Fungal populations decreased by 3 orders of magnitude in the first 2 days after the spill. The population levels gradually increased over the test and approached their pre-spill levels by the end of the experiment. The middle and lower soil bacterial levels recovered earlier than the upper soil layer. Middle soil bacteria levels were near pre-spill population densities by the 18th day. The bacteria in the lower soil layer recovered to the pre-spill levels by the 15th day. Fungal levels in the middle and lower soil layers reached their pre-spill numbers by the 22nd day, as shown in Figures D-7 and D-8.

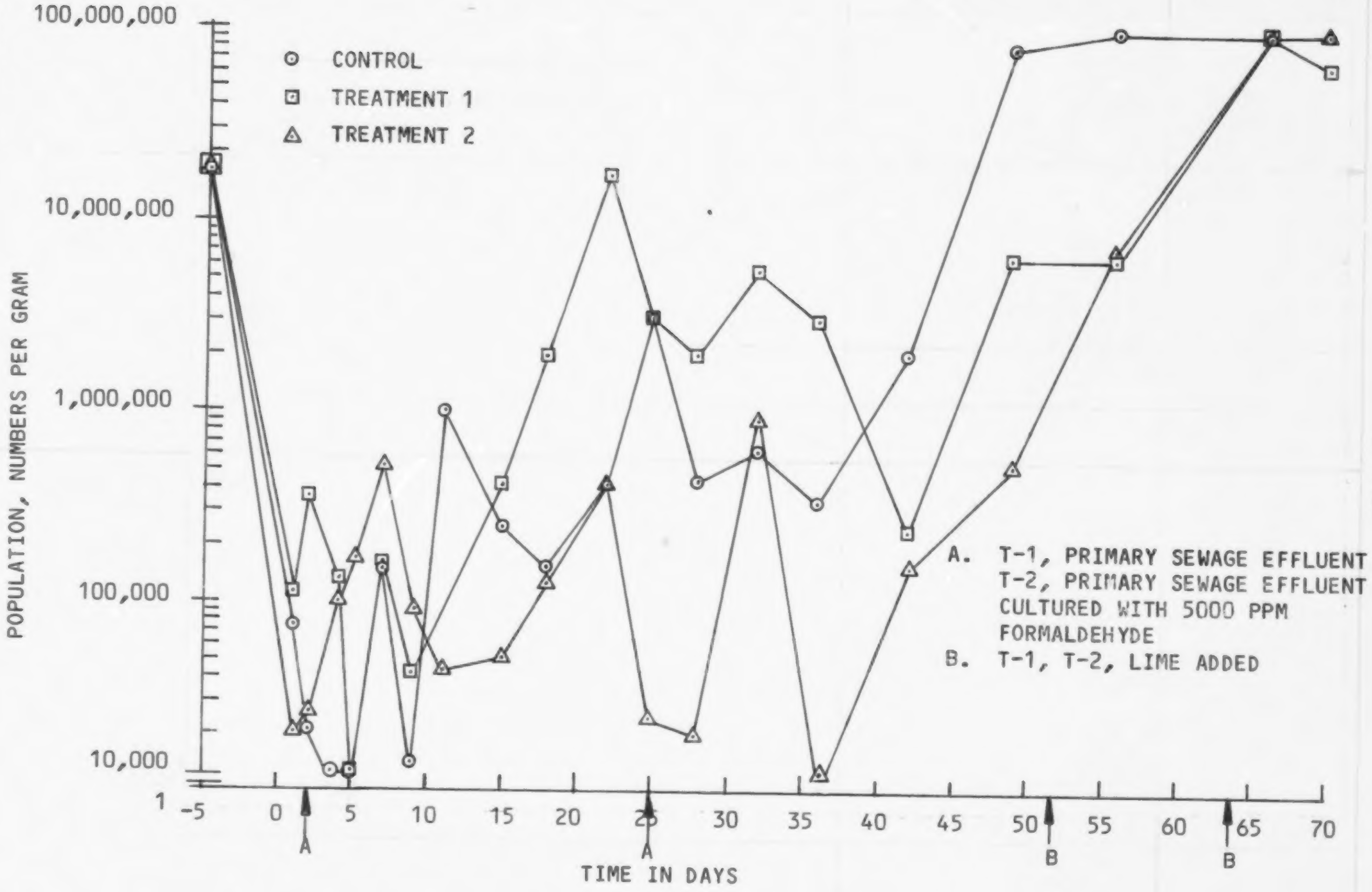


Figure 38. Upper level organic soil bacterial populations - formaldehyde spill.

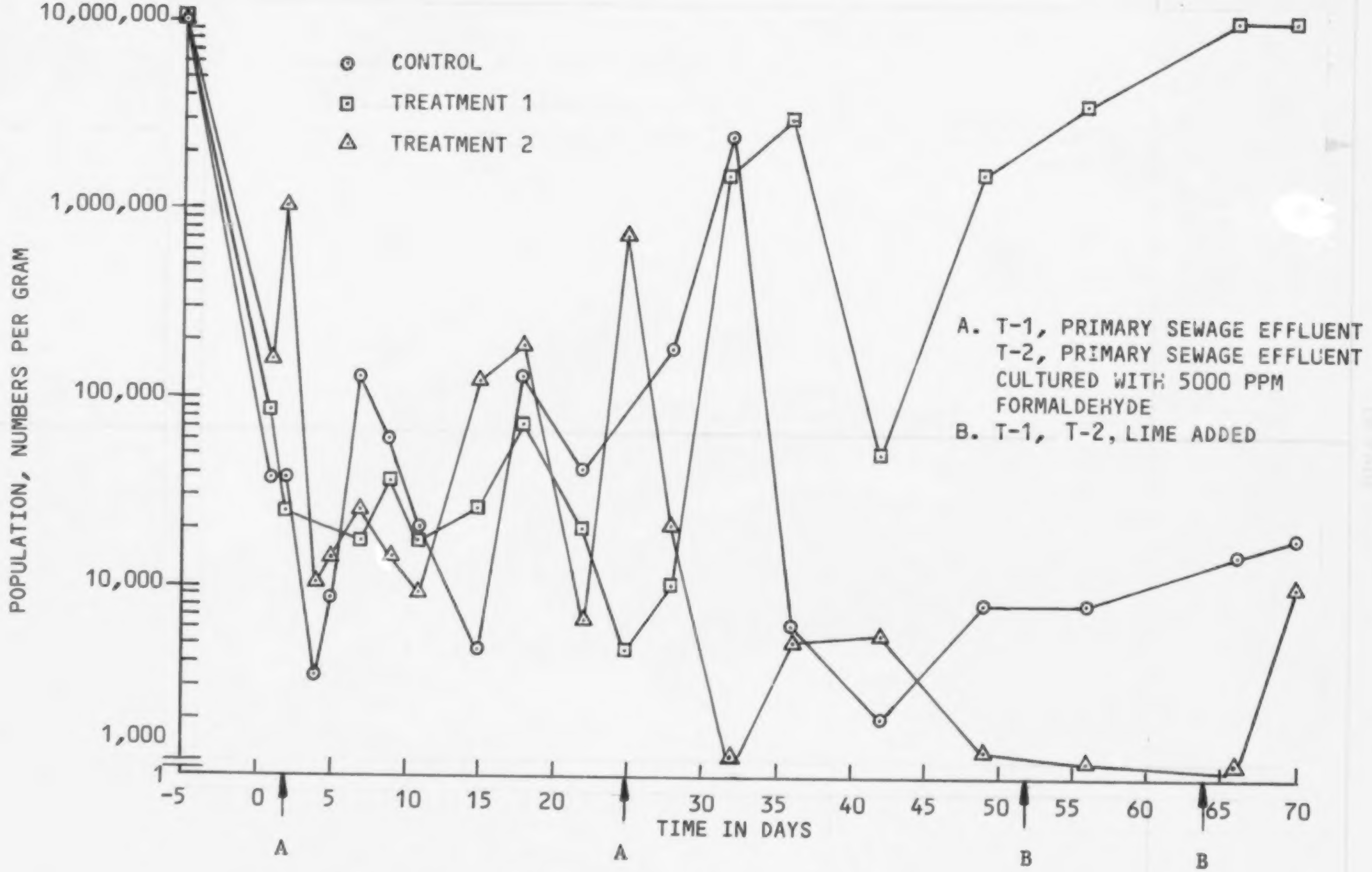


Figure 39. Upper level sandy soil bacterial populations - formaldehyde spill.

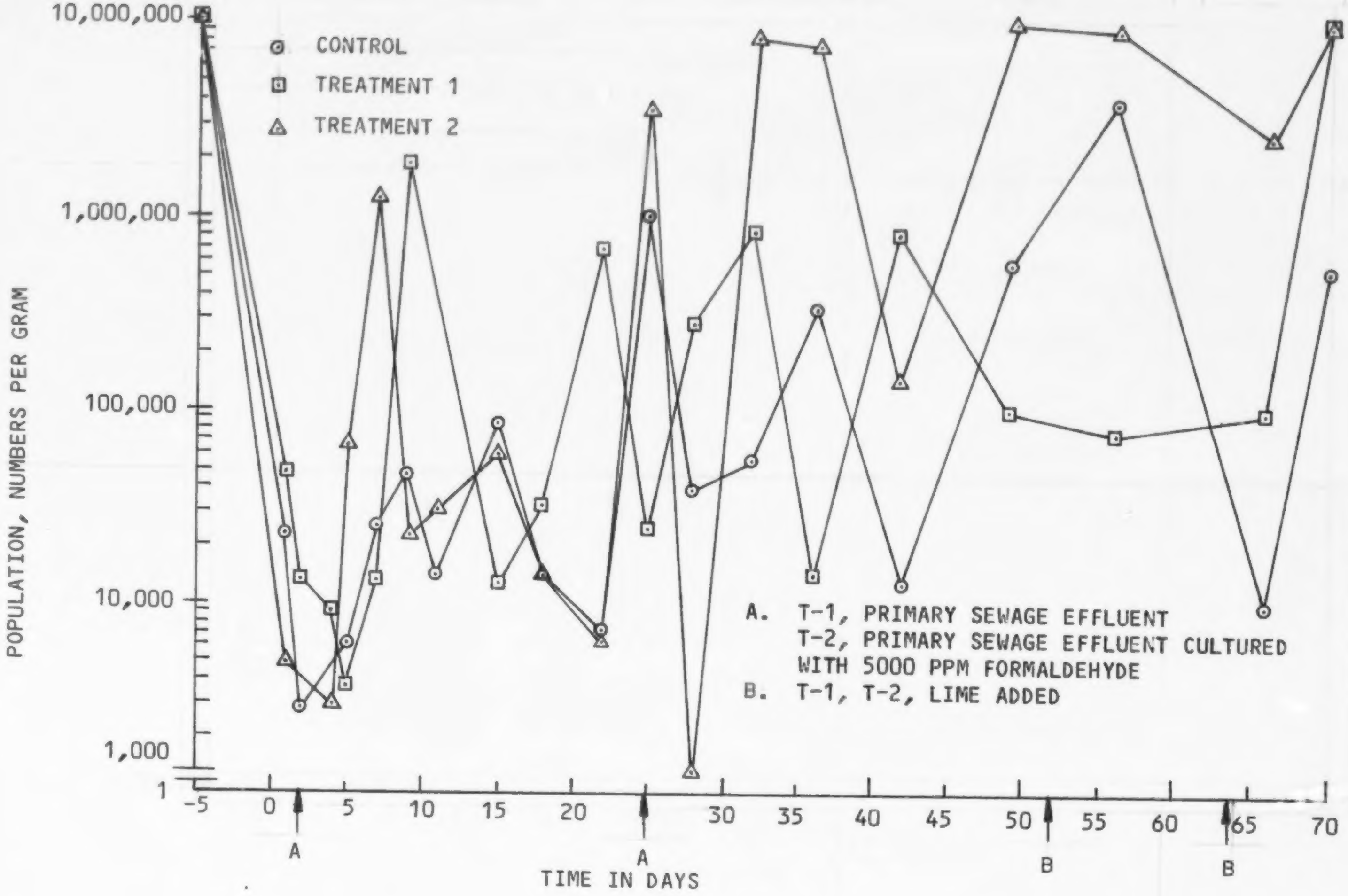


Figure 40. Upper level clay soil bacterial populations - formaldehyde spill.

TABLE 50. UPPER LAYER FUNGAL COUNTS ($X10^2$/gram soil) - FORMALDEHYDE SPILL

Soil Type and Treatment	Initial	DAY 1	2	4	5	7	9	11	15	18
Organic Control	2850.0	-	7.1	3.2	1.43	217.0	28.6	110.0	158.0	150.0
T-1	2850.00	1.05	4.0	77.0	25.0	320.0	40.0	12.5	110.0	14.3
T-2	2850.0	9.0	19.0	20.0	2.0	300.0	50.0	22.0	129.0	50.0
Sandy Soil Control	13600.0	5.6	32.0	5.0	3.33	62.5	20.0	66.7	45.0	11.1
T-1	13600.0	29.0	23.0	9.5	12.5	33.3	-	8.3	58.0	57.1
T-2	13600.0	-	-	71.40	25.0	25.0	143.0	9.0	110.0	62.5
Clay Soil Control	2550.0	2.0	2.9	13.0	10.0	25.0	9.0	-	60.0	14.3
T-1	2550.0	1.4	6.1	4.0	.90	12.5	-	16.7	50.0	-
T-2	2550.0	15.0	.68	14.0	11.1	1400.0	-	-	492.0	14.3

(continued)

TYPING GUIDE SHEET
EPA-287 (Cin.)
(4-76)

TABLE 50 (continued)

Soil Type and Treatment	DAY 22	25	28	32	36	42	49	56	66	70
Organic Control	56.0	133.0	63.0	50.0	210.0	63.0	114.0	155.0	-	33.0
T-1	106.0	200.0	700.0	1210.0	1000.0	-	133.0	130.0	1310.0	920.0
T-2	188.0	138.0	50.0	267.0	470.0	300.0	1556.0	tntc	10660.0	260.0
Sandy Soil Control	70.0	-	21.0	250.0	11.0	50.0	30.0	-	33.0	150.5
T-1	20.0	90.0	-	260.0	120.0	50.0	14.40	193.0	73.0	51.0
T-2	6.3	3.3	-	1000.0	70.8	2.5	72.9	0.66	65.0	25.7
Clay Soil Control	7.0	25.5	2.2	4.0	7.5	3.1	29.4	1.6	1.6	19.8
T-1	22.0	17.0	44.0	107.0	293.0	569.0	130.0	200.0	1490.0	260.0
T-2	6.3	2.0	1.1	2630.0	3080.0	1280.0	2640.0	6250.0	2500.0	11800.0

After the spill, the bacterial levels in the sandy soil chambers were reduced by 2-3 orders of magnitude. Bacterial levels in the upper soil layer were similar in all the chambers for the first 25 days. When the second microbial treatment was applied on day 25, the bacterial numbers in the upper and middle levels of the treatment-1 chamber increased rapidly to pre-spill populations. The treatment-2 and control chambers did not have similar increases in bacterial levels.

The fungal populations in the upper sandy soil layers are presented in Table 50. The fungal numbers per gram in the sandy soil decreased by 2-3 orders of magnitude after the spill. The fungal counts did not increase to the pre-spill levels during the test. In addition, no definite trends were observed in fungal counts after the treatments were applied.

Bacterial populations were reduced by 2-3 orders of magnitude in the upper layer of the clay soils by the formaldehyde spill. In the middle and lower layers, however, microbial levels were reduced by about one order of magnitude. Bacterial counts in the upper soil layer of all chambers were approximately the same over the first 25 days after the spill. After the second microbial treatment on day 25, the bacterial counts in the upper layer of chamber T-2 were higher than the control and T-1 chambers. The fungal populations in the upper clay soil layer are presented in Table 50. Fungal populations decreased by 3 orders of magnitude in the first two days after the spill. By day 32 the T-1 and T-2 chambers had fungal populations 1-3 orders of magnitude greater than the control.

In the middle soil layer, the control chamber bacterial levels were higher than those of T-1 and T-2 chambers. The middle layer fungal populations in the T-2 chamber increased after the treatment on day 25. Microbial levels in the lower soil level exhibited no trends during the test.

The recovery time of the microorganisms in the clay soils increased with depth. In the upper soil layer in chamber T-2, the bacteria reached pre-spill levels on day 49 as did the fungi on day 32. The other chambers either reached pre-spill levels at the end of the test or not at all.

Soil Formaldehyde Levels

The formaldehyde concentrations in the top soil layer are plotted versus time in Figures 41-43. The radiometric data in the upper soil layers are plotted in Figures D-13, D-14 and D-15 of Appendix D. The formaldehyde concentrations in the middle and lower soil layers are presented in Figures D-1 through D-6 of Appendix D. Generally, there was a rapid loss of formaldehyde from the upper soil layer in all chambers during the first 10 days. A concurrent drop in pH levels in the soil indicate that formaldehyde is oxidized to formic acid by microbial action or chemical reaction with soil constituents. The formaldehyde concentrations then decreased at a slower rate during the next 25-30 days. During this time period, bacterial levels slowly increased, thus indicating the build-up of formaldehyde metabolizing and formaldehyde resistant colonies.

Discussion of Results

The spill of formaldehyde was toxic to both the microorganisms in the soil

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD BEGIN SECTIONS HERE

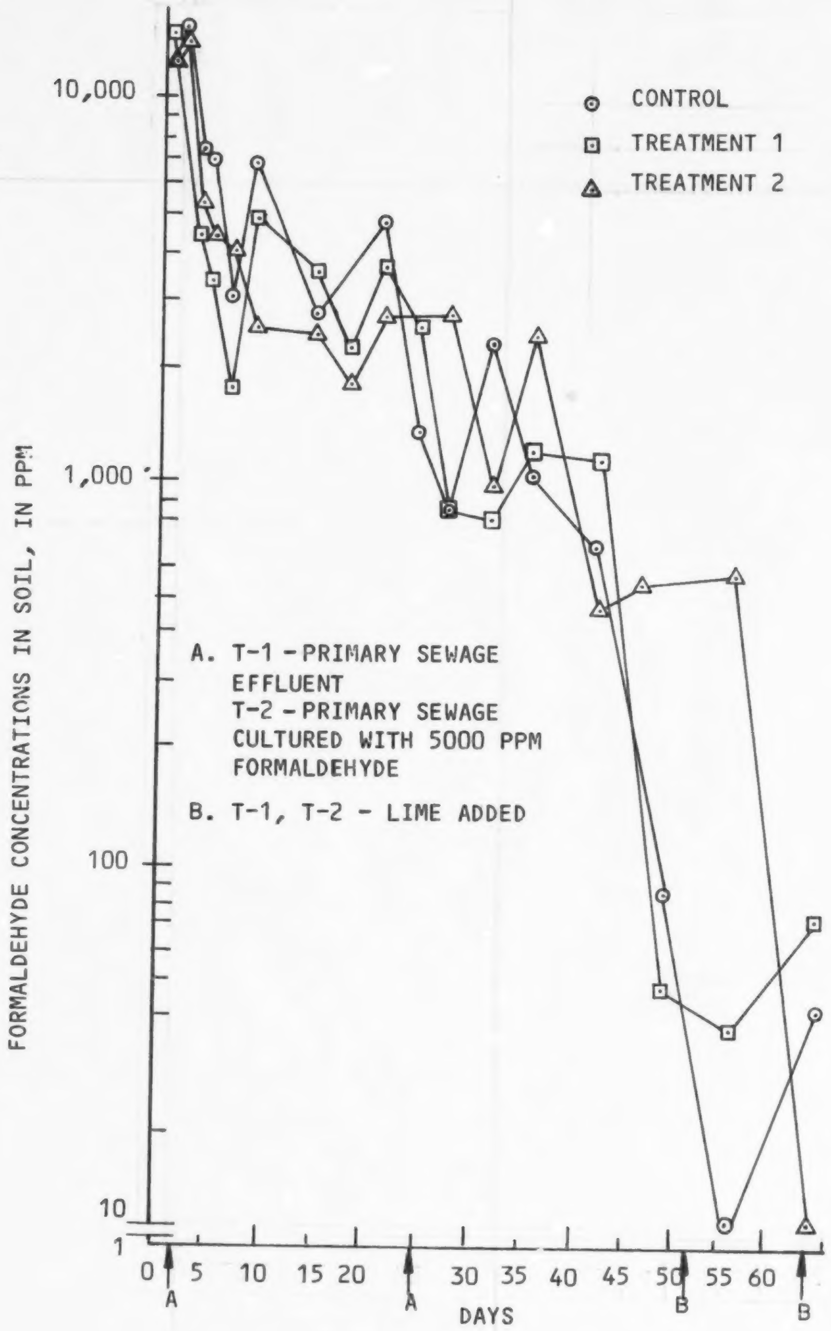


Figure 41. Formaldehyde concentrations in upper layer of organic soils.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

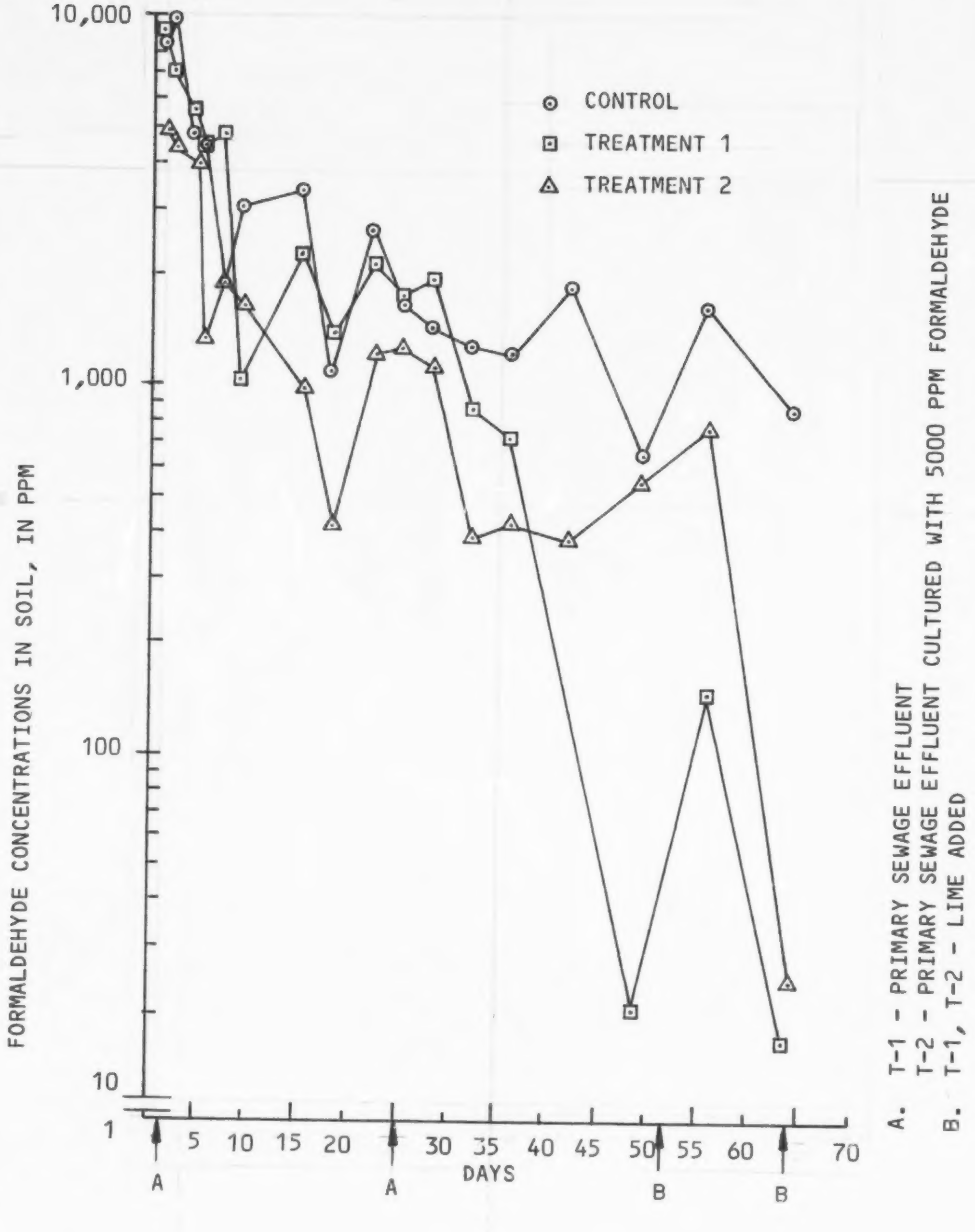


Figure 42. Formaldehyde concentrations in upper layer of sandy soils.

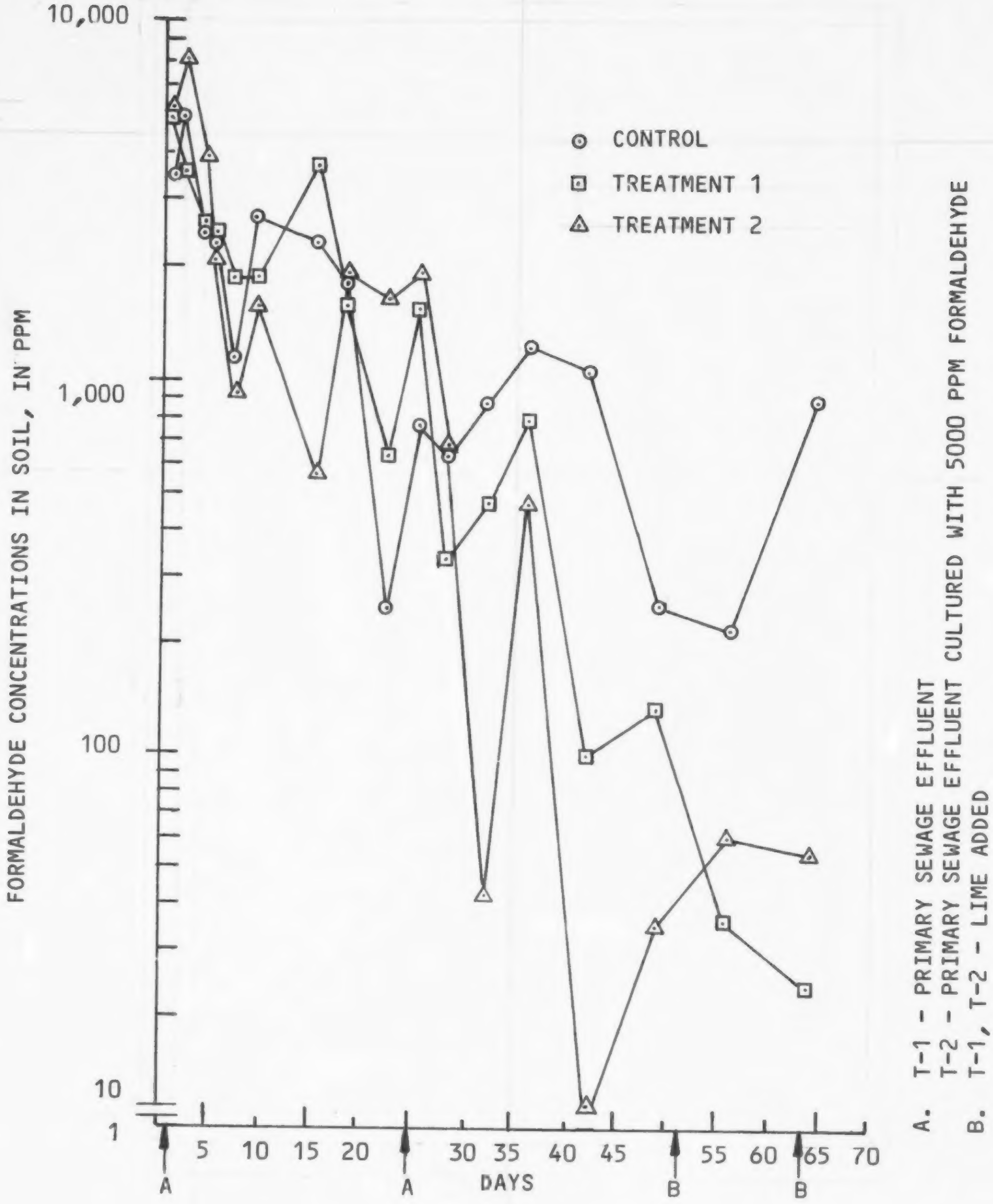


Figure 43. Formaldehyde concentrations in upper layer of clay soils.

and the plant life. Visible inspection of the chambers indicated that the grass was dead by the end of the second day after the spill.

In the organic soils, formaldehyde concentrations in the treated and control chambers were essentially the same for the first 25 days. The second microbial treatment applied on day 25 was again ineffective in accelerating the removal of formaldehyde from the soil as can be seen by comparing this formaldehyde removal rate with that observed in the control. The radiometric data in general confirms the formaldehyde analyses (See Figures D-13, D-14 and D-15 of Appendix D).

It appears that the microbial populations in both the control and treated chambers gained viability at approximately the same time. This recovery occurred when formaldehyde levels decreased to approximately 1000 ppm. Once the microbial population regained stability, the formaldehyde levels in the soil decreased rapidly. Thus, it appears that high formaldehyde concentrations (greater than 1000 ppm) are toxic to the soil microbial populations. However, once the formaldehyde is reduced to tolerable levels, the organic soil provides adequate nutrients for microbial metabolism.

The sandy soil upper layers exhibited only slight differences in formaldehyde levels between treated and control chamber over the initial 25 days (Figure 42). However, after the second treatment was applied on the 25th day, both treatment-1 and -2 soils had lower formaldehyde levels than the control. The T-1 chamber, treated with the unadapted primary sewage effluent, had the most rapid loss of formaldehyde. The middle sandy soil layers of the three chambers (Figure D-3) had approximately the same formaldehyde concentrations for the first 20 days. However, the formaldehyde concentrations in T-1 and T-2 continued to decline from day 20-66, while the concentration in the control chamber remained relatively stable. The treated and control chambers had no significant differences in formaldehyde concentrations at the lower level. The concentrations gradually declined throughout the study.

The formaldehyde levels in the upper layer of all the clay soil chambers were approximately the same during the first 25 days after the spill. The second treatment of microorganisms (day 25) increased the rate of depletion of the formaldehyde in the treated chambers. The T-2 chamber, receiving the Pseudomonas sp. culture had a faster rate of disappearance of formaldehyde concentration than in the T-1 chambers. However, the rate of disappearance of formaldehyde in the control chamber remained constant. By the 47th day, both treated chambers had upper layer formaldehyde concentrations less than 100 ppm, while the control chamber contained over 1000 ppm of formaldehyde in the soil.

The middle soil layer in the clay chambers had initial formaldehyde concentrations between 500-1000 ppm. The T-2 chamber middle layer reached 0 ppm of formaldehyde on day 52. The lower clay soil layers (Figure D-6) showed no significant trends in formaldehyde concentration that could be attributed to the treatments used. All lower clay layers had formaldehyde concentrations less than 30 ppm on the 46th day.

Regression lines were fitted to the formaldehyde data from the upper soil layers by the least-squares method. The slopes, or rate of loss of formaldehyde, are presented in Table 51. Regression lines were also fitted to the ^{14}C net counts per minute versus time. The slopes of these lines are presented in Table 52.

The higher rate of removal of formaldehyde from the sandy T-1 and clay T-2 chambers correlates with the loss of ^{14}C activity in the chambers.

LAND RESTORATION TECHNIQUE II - ANILINE SPILL

Soil pH

The soil pH values for the organic, sandy and clay soils with core depth over time are presented in Tables E-2, E-3 and E-4 of Appendix E. The pH levels in the upper level organic soil control and T-1 chambers remained fairly stable with the majority of the values between 7 and 7.5. The T-2 chamber, pH values in the upper layers were typically between 6 and 7.

TABLE 51. RATE OF FORMALDEHYDE LOSS (PPM/DAY)

	Soil Types		
Chamber	Organic	Sandy	Clay
Control	145	82	48
T-1	110	90	64
T-2	122	51	72

TABLE 52. LOSS RATE OF C-14 ACTIVITY (NET CPM/DAY)

	Soil Types		
Chambers	Organic	Sandy	Clay
Control	2.3	1.3	0.7
T-1	4.5	1.1	1.0
T-2	1.8	0.5	1.0

Sandy soil pH levels had trends similar to those measured in the organic soil chambers. The control chamber sandy soil had near neutral pH values, typically between 6.9 and 7.3. The T-1 chamber soil pH levels were more acidic with the majority of the values between 6.3 and 6.8. The typical soil pH values in the T-2 chamber ranged from 5.5-6.6.

The clay soil pH values in the control chamber were erratic and predominantly acidic. The T-1 chamber soil pH values typically ranged between 5.5 and 6.3. The majority of the soil pH values in the T-2 chamber ranged between 5.8 and 6.9.

Soil Moisture Content

The percent moisture as a function of depth and time for the organic, sandy and clay soils are presented in Tables E-5, E-6 and E-7 of Appendix E. For the organic soil chambers, there were no significant differences in moisture levels between chambers. The typical upper layer moisture content ranged between 23 and 36%. The typical upper layer moisture content in the sandy soil chambers ranged from 20 to 28%. The majority of the clay soil upper layer moisture content values ranged from 12 to 20%.

Microbial Populations

The soil bacterial populations in the upper layers of the organic, sandy, and clay soils as a function of time are presented in Figures 44-46.

Bacterial levels in the upper layer of the organic soil decreased by a factor of 10 after the aniline spill. The bacterial populations in all the chambers were relatively similar for the next ninety days. After the treatment with the mixed microbial population on day 96, the bacterial levels in the T-1 chamber were approximately ten times higher than the control chamber for the remainder of the experiment.

After the aniline spill, bacterial levels decreased in the upper layers of the sandy soils decreased by factors of 4 to 50. The bacterial levels in the control and T-1 chambers gradually increased over the remainder of the experiment. The bacterial levels in the T-2 chamber decreased by about 10 times after the addition of 15% hydrogen peroxide on day 42. The bacterial population in the T-2 chamber gradually recovered and by day 120 were similar to the other sandy soil chambers.

The bacterial levels in the clay soil decreased by 10-100 times after the aniline spill. The bacterial population recovered after about 30 days. After day 60, the bacterial levels in chamber T-1 were greater than the control and the control bacterial levels were greater than the chamber T-2.

Soil Aniline Levels

The aniline concentrations versus time for the upper layers of the organic, sandy, and clay soils chambers are presented in Figures 47-49. The aniline concentrations in the middle soil levels are presented in Table E-8 of Appendix E.

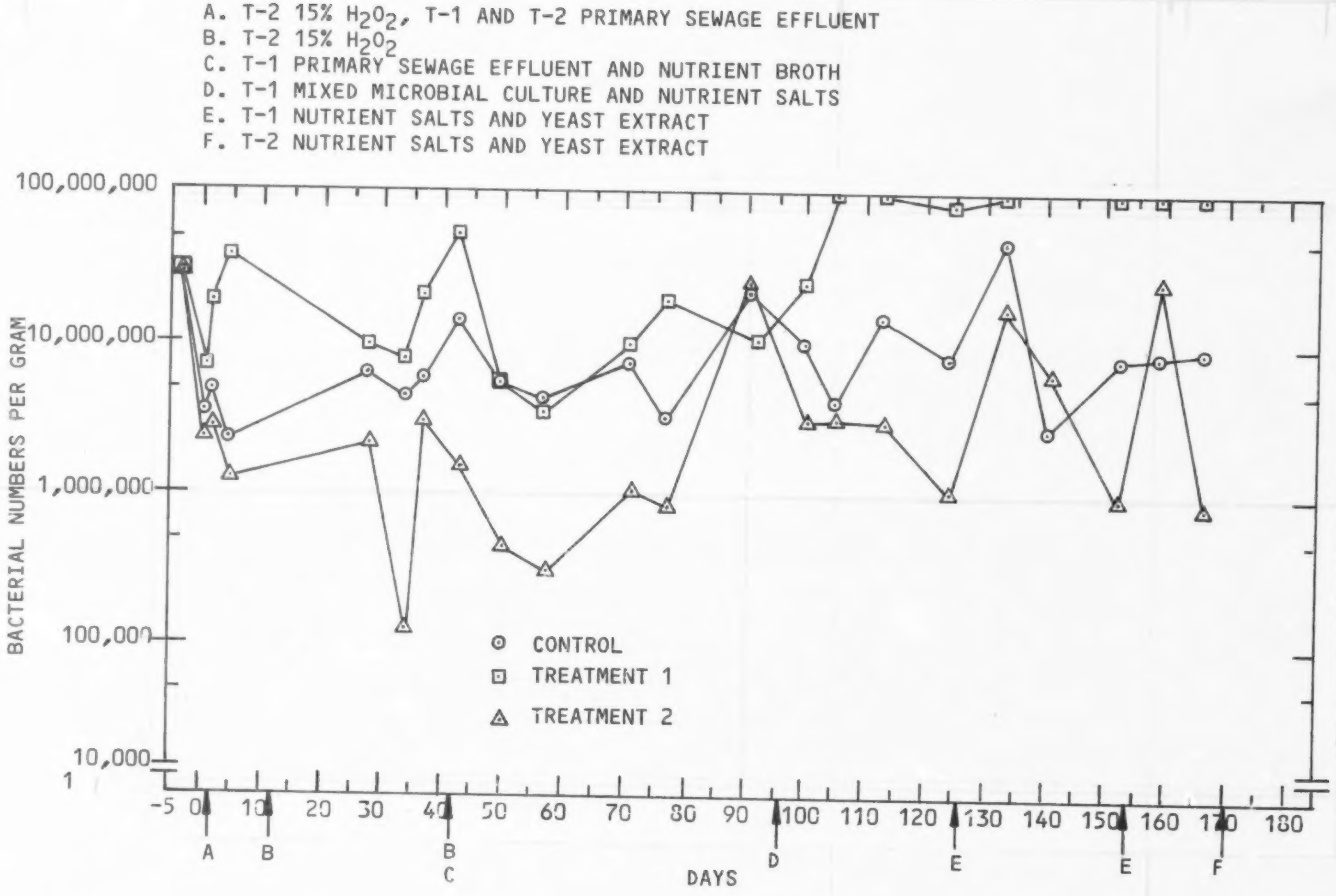


Figure 44. Upper level organic soil bacterial populations - aniline spill.

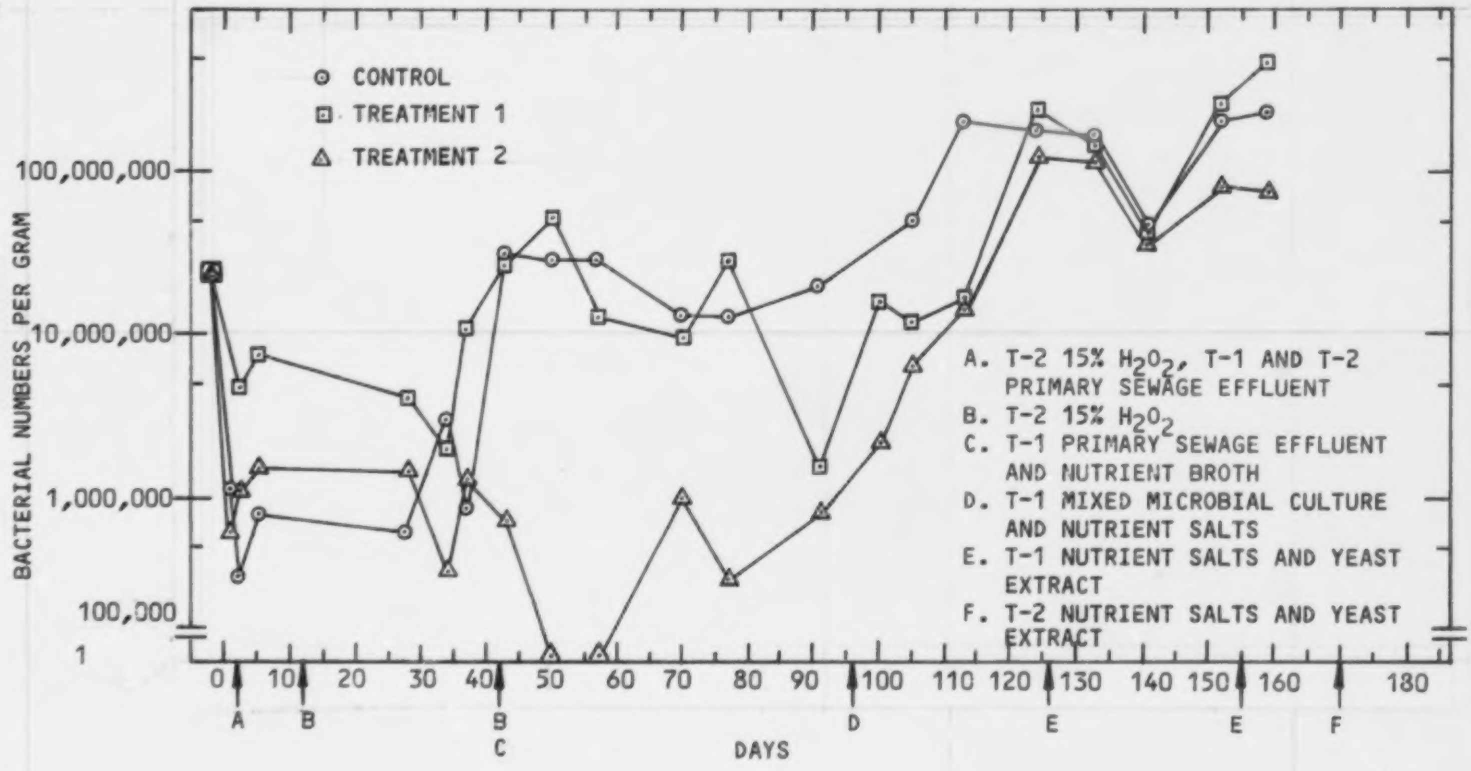


Figure 45. Upper level sandy soil bacterial populations - aniline spill.

A. T-2 15% H_2O_2, T-1 AND T-2 PRIMARY SEWAGE EFFLUENT
B. T-2 15% H_2O_2
C. T-1 PRIMARY SEWAGE EFFLUENT AND NUTRIENT BROTH
D. T-1 MIXED MICROBIAL CULTURE AND NUTRIENT SALTS
E. T-1 NUTRIENT SALTS AND YEAST EXTRACT
F. T-2 NUTRIENT SALTS AND YEAST EXTRACT

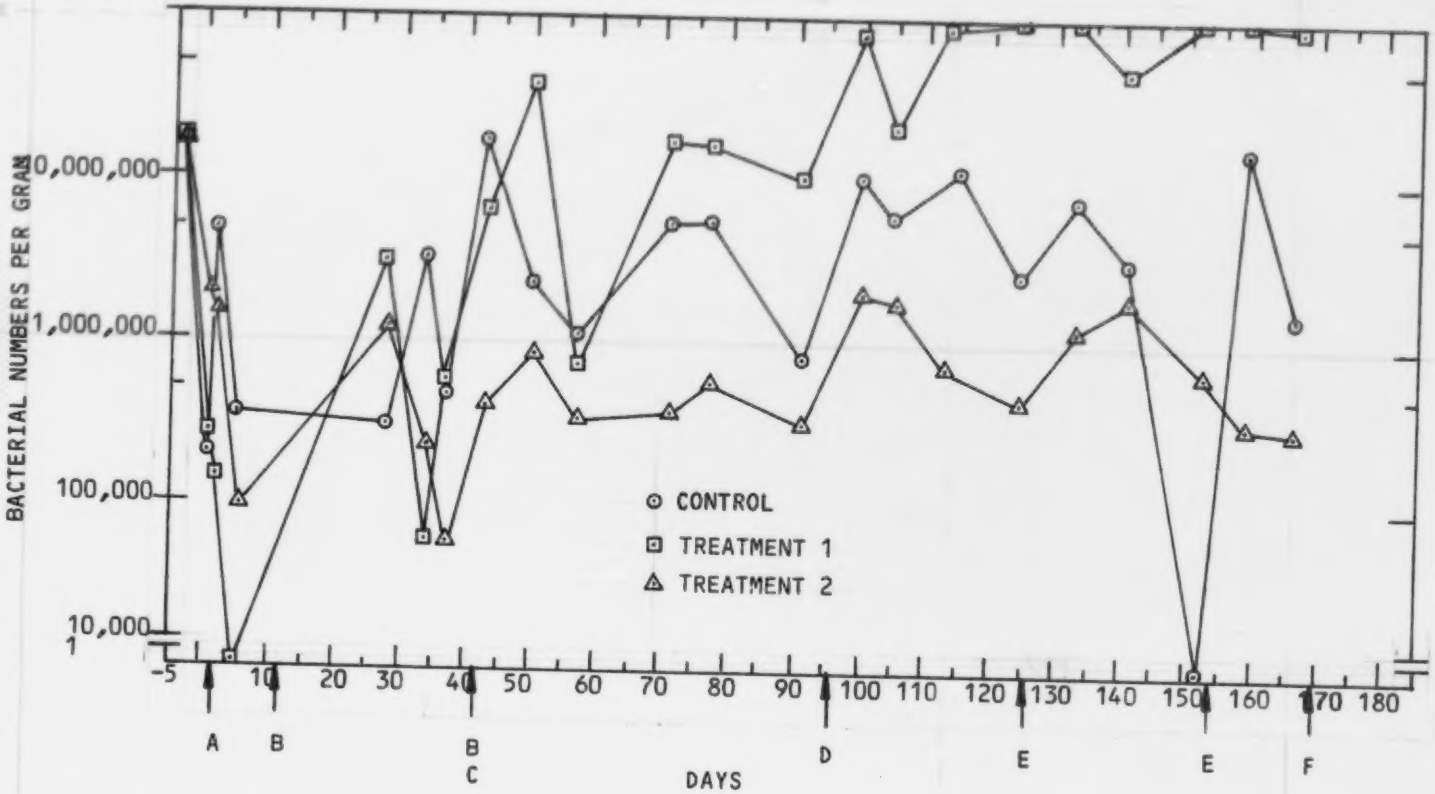


Figure 46. Upper level clay soil bacterial population - aniline spill.

A. T-2 15% H_2O_2, T-1 AND T-2 PRIMARY SEWAGE EFFLUENT
B. T-2 15% H_2O_2
C. T-1 PRIMARY SEWAGE EFFLUENT AND NUTRIENT BROTH
D. T-1 MIXED MICROBIAL CULTURE AND NUTRIENT SALTS
E. T-1 NUTRIENT SALTS AND YEAST EXTRACT
F. T-2 NUTRIENT SALTS AND YEAST EXTRACT

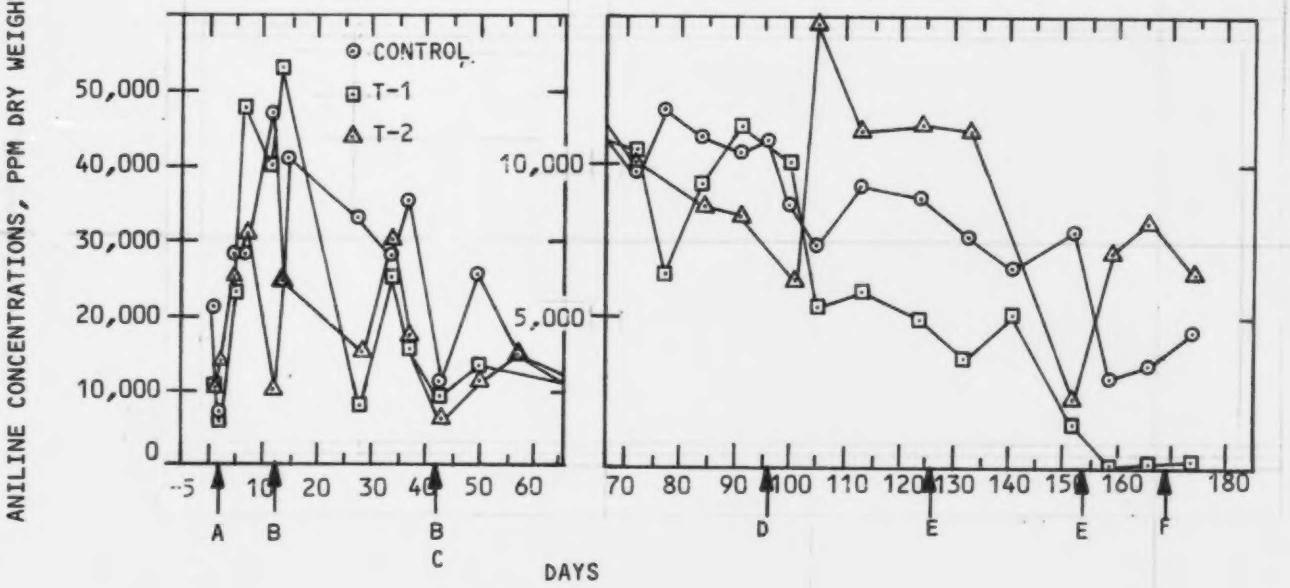


Figure 47. Aniline concentrations - upper level of organic soil.

TYPING GUIDE SHEET
EPA-287 (Cin.)
(4-76)

A. T-2 15% H_2O_2, T-1 AND T-2 PRIMARY SEWAGE EFFLUENT

B. T-2 15% H_2O_2

C. T-1 PRIMARY SEWAGE EFFLUENT AND NUTRIENT BROTH

D. T-1 MIXED MICROBIAL CULTURE AND NUTRIENT SALTS

E. T-1 NUTRIENT SALTS AND YEAST EXTRACT

F. T-2 NUTRIENT SALTS AND YEAST EXTRACT

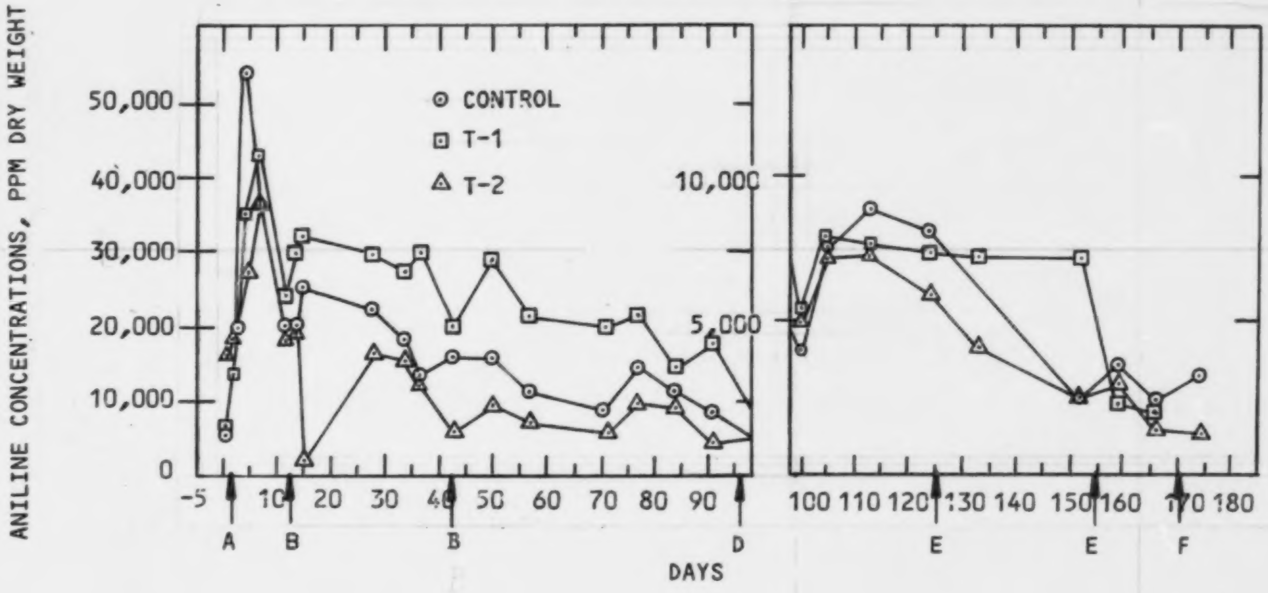


Figure 48. Aniline concentrations - upper level of sandy soils.

A. T-2 15% H_2O_2, T-1 AND T-2 PRIMARY SEWAGE EFFLUENT

B. T-2 15% H_2O_2

C. T-1 PRIMARY SEWAGE EFFLUENT AND NUTRIENT BROTH

D. T-1 MIXED MICROBIAL CULTURE AND NUTRIENT SALTS

E. T-1 NUTRIENT SALTS AND YEAST EXTRACT

F. T-2 NUTRIENT SALTS AND YEAST EXTRACT

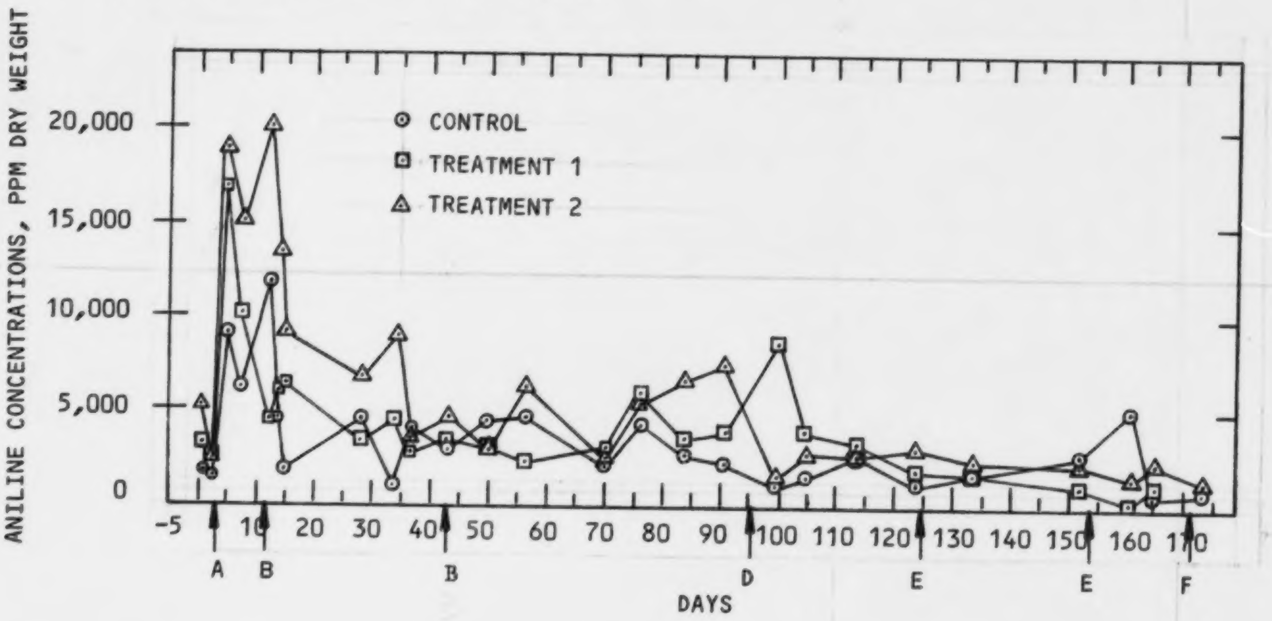


Figure 49. Aniline concentrations - upper level of clay soil.

Discussion of Results

The aniline spill was toxic to soil microbes and plants. The grasses in the chamber were dead by the end of the fourth day after the spill.

The initial treatments with hydrogen peroxide and primary sewage effluent, T-2, or primary sewage effluent alone, T-1, were relatively ineffective in reducing aniline levels in the organic soil. However, on day 96, the T-1 chamber was treated with a mixed culture of microorganisms and a nutrient salt solution. By day 113, the aniline levels in the T-1 chambers were significantly lower than the control chamber. The addition of nutrient salt and yeast extract solutions on day 126 and 154 continued to reduce the aniline levels in the T-1 chamber. By day 160, aniline levels in the T-1 chamber were less than 100 ppm. The treatments applied to the T-2 chamber were not effective in reducing the aniline concentrations in the soil.

The hydrogen peroxide treatments reduced the aniline concentrations in the T-2 sandy chamber by 20-40%. The T-2 chamber had the lowest aniline concentrations for the remainder of the experiment. The initial addition of primary sewage effluent (treatment-1) to the sandy soil chamber was ineffective. However, after the addition of the mixed microbial culture and the nutrient salts on day 96, the aniline level decreased by 6000-8000 ppm. Another decrese in the soil, aniline concentration in the T-1 chamber was observed after the nutrient salts and yeast extract were added on day 154.

None of the treatments were effective in accelerating the removal of aniline from the clay soil. Aniline levels in all three chambers decreased at a similar rate.

Half-lives of aniline concentrations in the organic and sandy soils are presented in Table 53. The half-lives were calculated assuming a first order decay. For the organic soil, the aniline concentration in the control chamber on day 12 was used as the initial value for the calculations. The half-life of aniline in the T-1 chamber was about 1/2 the half-lives in the control and T-2 chambers.

The half-lives for the sandy soil chambers were separated in parts. In the first part of the experiment (days 7-91), the T-2 chamber which received hydrogen peroxide had the shortest half-life. However, in the second part of the experiment (days 91-166), the T-1 chamber had the shortest half-life. The T-1 chamber received the adapted mixed microbial culture and nutrient salts during this period.

TABLE 53. HALF-LIVES OF ANILINE IN ORGANIC AND SANDY SOILS

Chamber	Organic Soil Days 12-166	Sandy Soil Days 7-91	Sandy Soil Days 91-166
Control	44	39	45
T-1	19	63	24
T-2	58	28	49

EPA Form 2350-4 (4-80)
[PREVIOUSLY CIN: EPA FORM 287]
TYPING GUIDE SHEET

LAND RESTORATION TECHNIQUE III - CHLORDANE SPILL

Soil pH

The data on the soil pH levels as a function of depth and time, for the chlordane experiment, are presented in Table F-2 or Appendix F. All the T-2 chambers, which received the lime, had pH levels from 7.3-9.2. The organic and sandy soil control chambers had near neutral pH values, while the control clay soil chamber had pH values near 9. The T-1 chambers organic soil had pH values near neutral, the sandy soil had pH values near 8 and the clay soil had acidic pH levels.

Soil Moisture Content

The data on the percent moisture levels in the soils for the chlordane experiments are presented in Table F-3 of Appendix F. The organic soil moisture levels ranged from 11-35%. The sandy soil moisture levels ranged from 13-30% and the clay soil from 10-25%.

Microbial Populations

The chlordane spill did not affect the bacterial populations in the soils. These populations as a function of time are presented in Table F-4 of Appendix F. After the spill, bacterial populations increased in all chambers. Generally, the T-1 chambers had the highest bacterial populations.

Soil Chlordane Levels

The chlordane concentrations in the organic, sandy and clay soils as a function of time are shown in Figures 50-52. The data from the organic and sandy soils are very erratic. The clay data are somewhat better. The erratic data are due either to bad extraction or non-representative subsamples.

Discussion of Results

The chlordane spill was not significantly toxic to soil microbes. However, it was toxic to the grass in the chambers. The grass was completely dead within 48 hours after the spill.

In general, there was no loss of chlordane from the clay or the organic soils. The organic T-1 soil showed a slight decline in chlordane, however, the data are too scattered to draw any definite conclusions. In all sandy soil upper layers chlordane concentrations decreased. The control and treated chambers appeared to lose chlordane at a similar rate. The radiation levels in the sandy soils (see Table 54) also show a gradual decrease in activity. No chlordane was found in the traps or carbon filters or in any of the chambers. The ^{14}C levels in the bubblers from the sandy chambers were below the detection limits.

From the data, it appears that chlordane is persistent in the soils with the possible exception of the sandy soils. However, it is not known if the apparent decrease in chlordane levels was due to degradation or volatilization. No

A. T-1 ADDITION OF MICROBIAL CULTURE AND NUTRIENT SALTS
T-2 ADDITION OF LIME, MICROBIAL CULTURE AND NUTRIENT SALTS

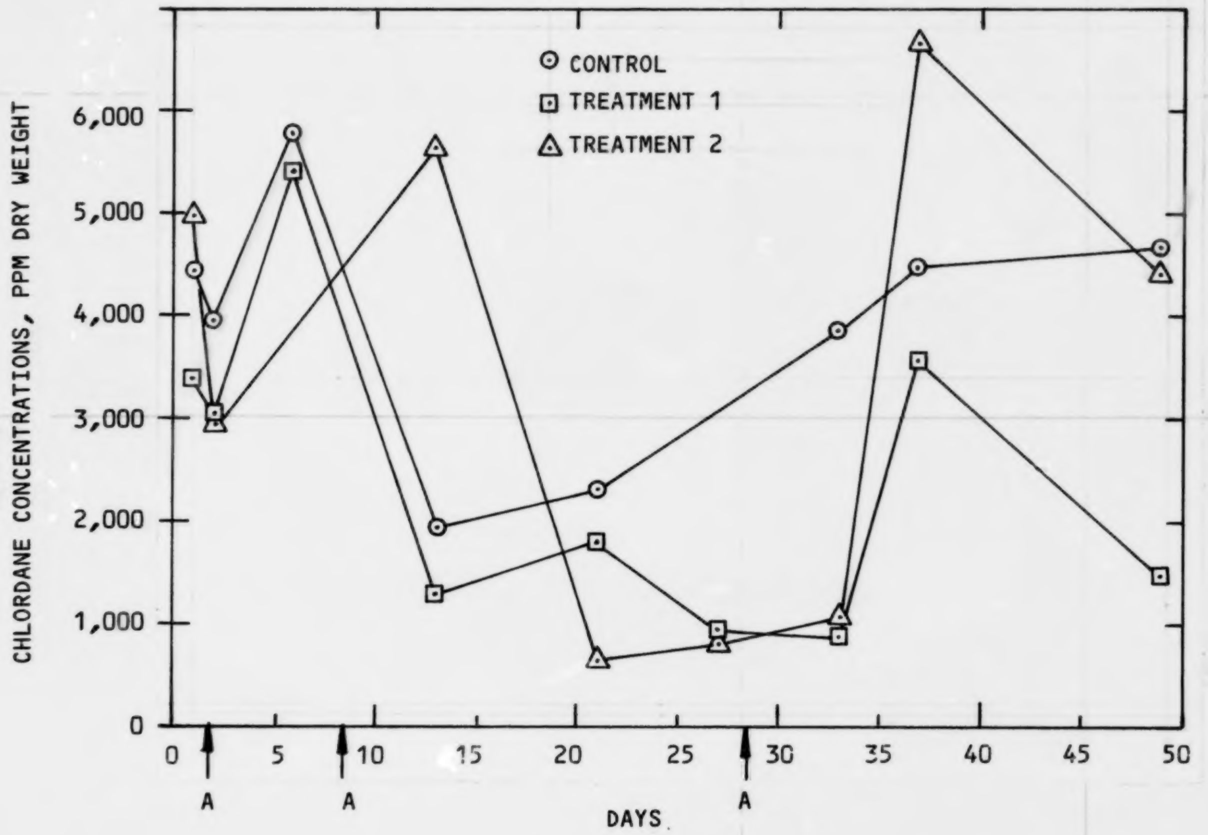
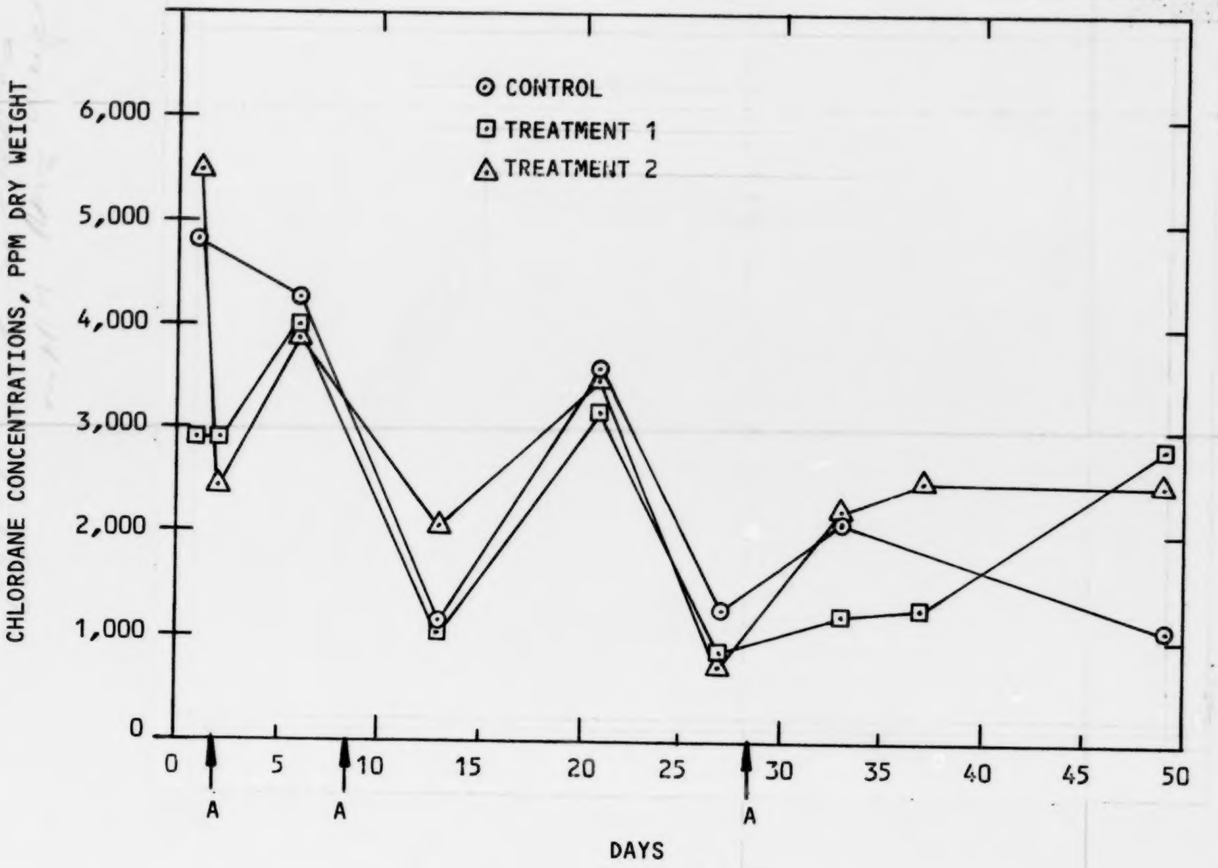


Figure 50. Chlordane concentrations in upper level of organic soil.

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
DROPPED HEAD, BEGIN SECTIONS HERE
CENTER OF PAGE
TOP OF IMAGE AREA
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)



A. T-1 ADDITION OF MICROBIAL CULTURE AND NUTRIENT SALTS
T-2 ADDITION OF LIME, MICROBIAL CULTURE AND NUTRIENT SALTS

Figure 51. Chlordane concentrations in upper level of sandy soil.

A. T-1 ADDITION OF MICROBIAL CULTURE AND NUTRIENT SALTS
T-2 ADDITION OF LIME, MICROBIAL CULTURE AND NUTRIENT SALTS

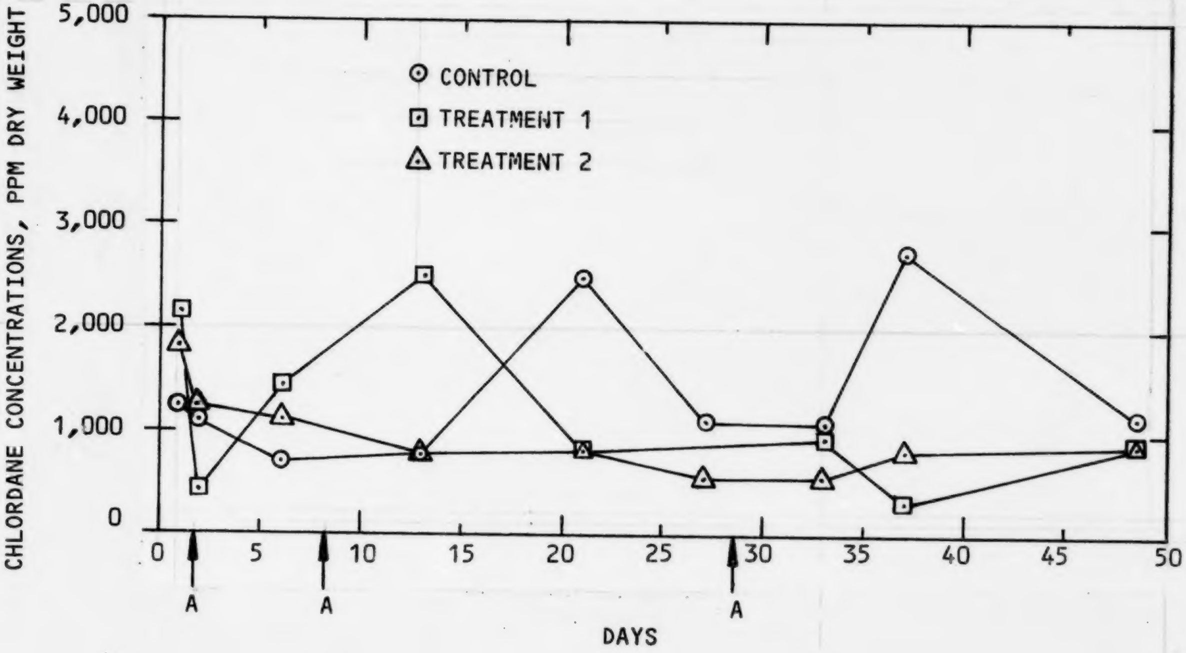


Figure 52. Chlordane concentrations in upper level of clay soil.

EPA-287 (Cin.)
(4-76)

TABLE 54. ^{14}C RADIATION COUNTS IN SANDY SOILS TREATED WITH ^{14}C - CHLORDANE

	Days									
Chamber Treatment	1	2	6	13	21	27	33	37	49	175
Control	219	146	137	93	92	56	172	50	77	27
T-1	-	223	250	99	101	70	72	83	150	26
T-2	170	168	202	120	109	279	118	194	72	17

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN EPA FORM 287)
TYPING GUIDE SHEET

degradation products were found in the GC traces, however, column conditions and/or extraction conditions may have not been favorable for their detection.

LAND RESTORATION TECHNIQUE III - 2,4-DINITROPHENOL SPILL

Soil pH

The soil pH levels in 2,4-dinitrophenol chambers are presented in Table G-2 of Appendix G. The initial organic soil pH values were near neutral. The sandy and clay initial pH values were acidic. The lime added to the treated chambers increased the pH of the soil by 2-3 units.

Soil Moisture Content

The soil percent moisture data are presented in Table G-3 of Appendix G. The percent moisture values ranged from 23-34% in the organic soils; 23-32% in the sandy soils;11-28% in the clay soils.

Microbial Populations

Soil bacterial populations are presented in Table G-4 of Appendix G. The addition of the 2,4-dinitrophenol to the soil reduced the bacterial population by one-half to 100-fold. By the 12th day the bacterial population in the treated clay soil chamber had recovered to pre-spill levels. However, the organic and sandy soil bacterial levels did not return to pre-spill levels before the end of the test.

Soil, 2,4-Dinitrophenol Concentrations

The 2,4-dinitrophenol levels in the organic soil are presented in Figure 53. The erratic chemical concentration values were in part due to the clumping of the dinitrophenol after watering of the organic soil. Dinitrophenol conentrations in the upper layer of both organic soil chambers were less than 2000 ppm on day 62.

The sandy soil 2,4-dinitrophenol concentration-time data are presented in Figure 54. The dinitrophenol concentrations in the control and treated chambers decreased a similar rate during the experiment. The 2,4-dinitrophenol concentrations were less than 2000 ppm in both chambers after day 22.

The 2,4-dinitrophenol concentrations in the clay soils are presented in Figure 55. The treated clay soil chamber had 2,4-dinitrophenol levels less than 1000 ppm by the end of the test. If it is assumed that the initial sample from the control chamber is not representative (both chambers received the same amount of dinitrophenol), then the treated clay chamber had an accelerated rate of loss of dinitrophenol from the soil.

Discussion of Results

2,4-Dinitrophenol is a good example of a compound which can produce a relatively persistent, slightly water soluble chemical spill on land. This chemical killed the grass cover in the chamber within 5 days after the spill. It also depressed the soil microbial populations.

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 287)
TYPING GUIDE SHEET

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD; BEGIN SECTIONS HERE

A. ADDITION OF LIME, MICROBIAL CULTURE, NUTRIENT SALTS, AND YEAST EXTRACT TO TREATED CHAMBERS

B. ADDITION OF MICROBIAL CULTURE, NUTRIENT SALTS AND YEAST EXTRACT TO TREATED CHAMBERS

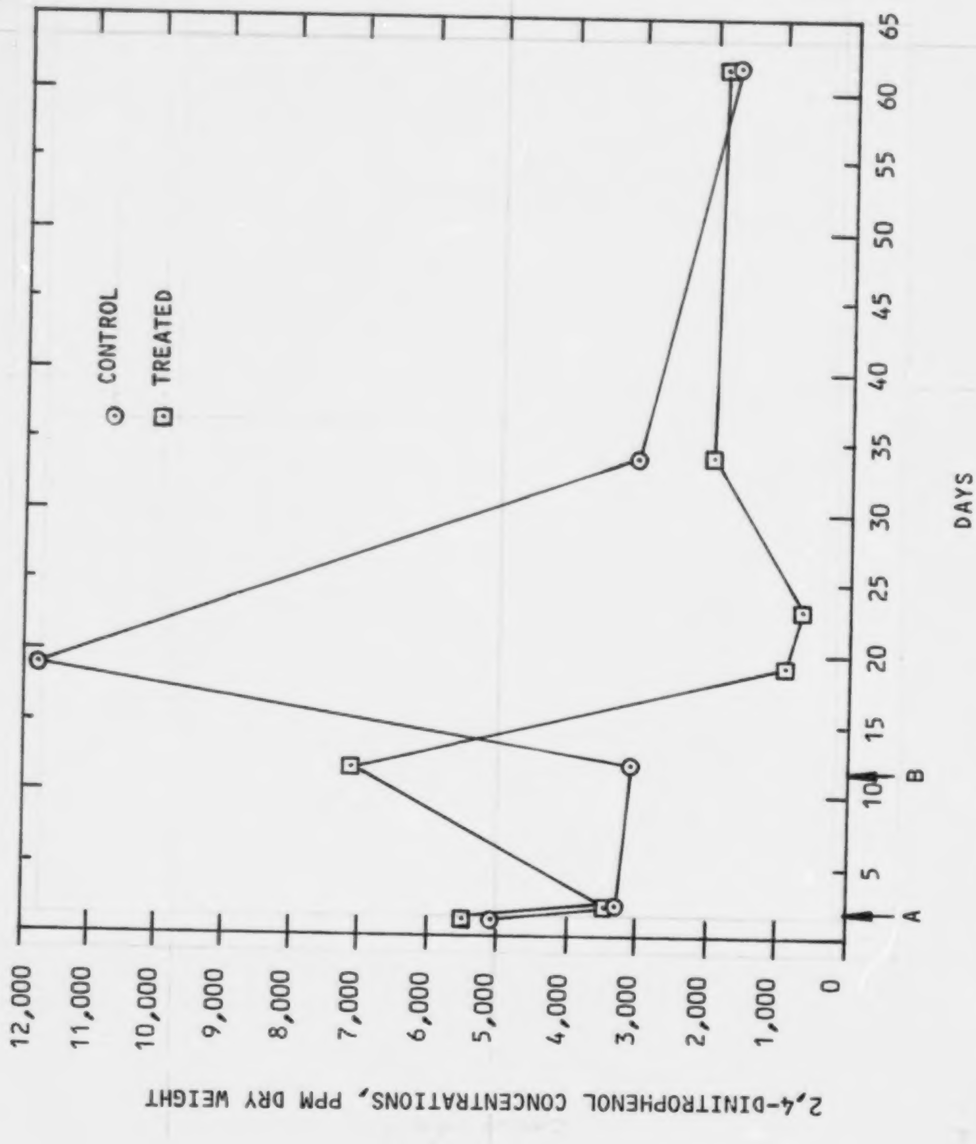


Figure 53. 2,4-Dinitrophenol concentrations in the upper level of the organic soils.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA - OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-287 (Cin.) (4-75)

BEGIN FIRST LINE OF TEXT HERE
TYPING GUIDE SHEET
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD BEGIN SECTIONS HERE

A. ADDITION OF LIME, MICROBIAL CULTURE, NUTRIENT SALTS AND YEAST EXTRACT TO TREATED CHAMBER

B. ADDITION OF MICROBIAL CULTURE, NUTRIENT SALTS AND YEAST EXTRACT TO TREATED CHAMBER

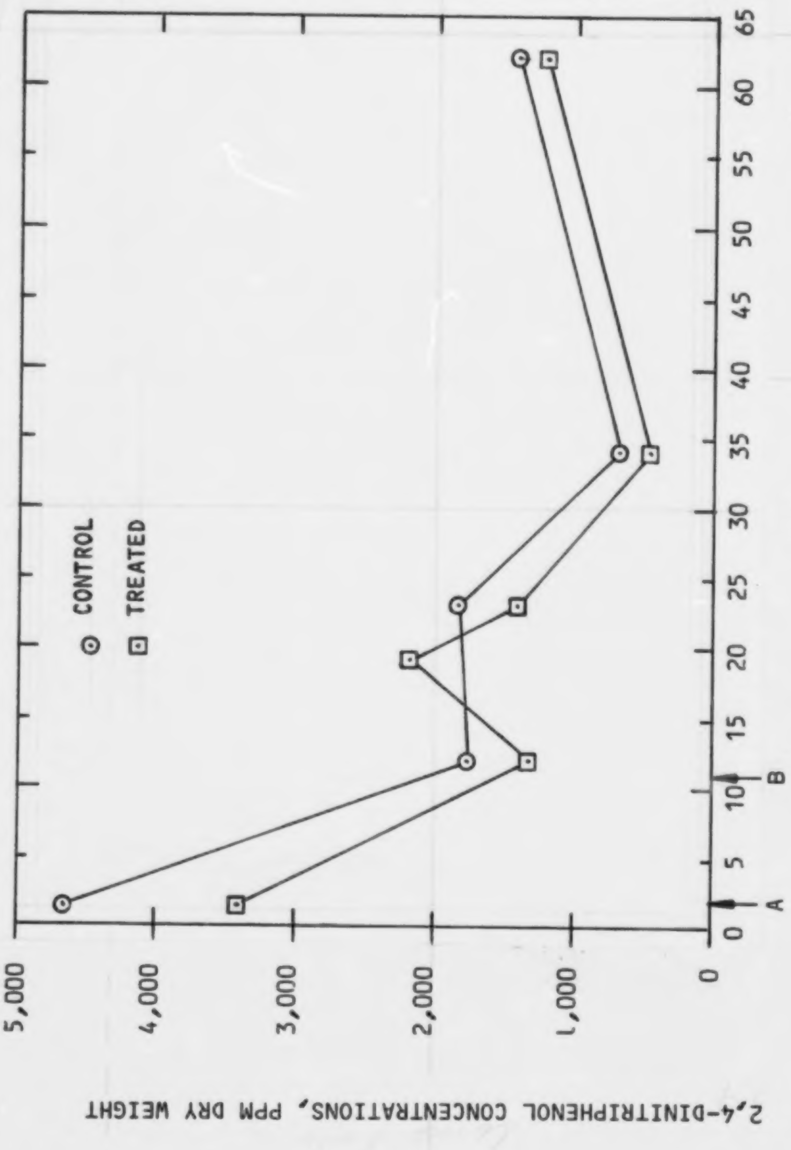


Figure 54. 2,4-Dinitrophenol concentrations in the upper level of the sandy soils.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS

PAGE NUMBER
EPA-287 (Cin.)
(4-75)

A. ADDITION OF LIME, MICROBIAL CULTURE, NUTRIENT SALTS AND YEAST EXTRACT TO TREATED CHAMBER
B. ADDITION OF MICROBIAL CULTURE, NUTRIENT SALTS AND YEAST EXTRACT TO TREATED CHAMBER

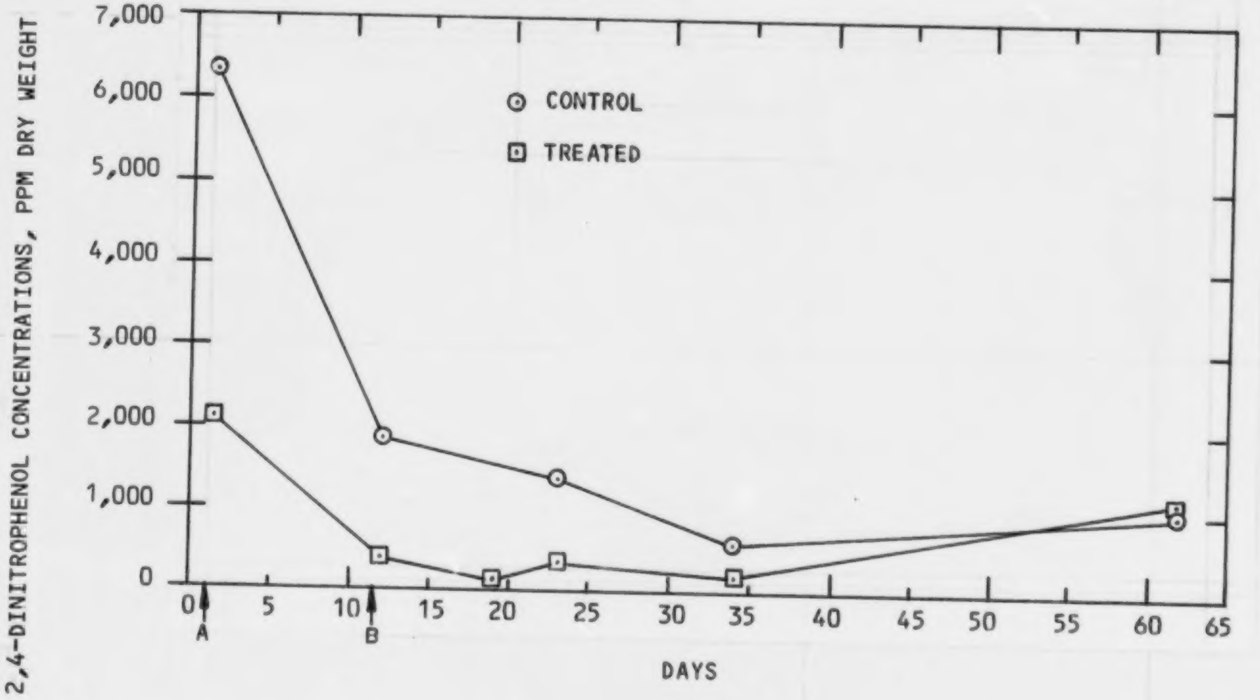


Figure 55. 2,4-Dinitrophenol concentrations in the upper level of the clay soils.

The variation in the 2,4-dinitrophenol concentrations in the organic soil chambers was due in part to nonrepresentative sampling. Sampling problems were caused by the clumping of the 2,4-dinitrophenol particles in the organic soil chambers.

The 2,4-dinitrophenol concentrations in the upper layer of the treated and control sandy soil chambers are similar throughout the experiment. The 2,4-dinitrophenol concentrations decrease from near 4,000 ppm at day 1 to 1200-1400 ppm at day 62. The treatments were not effective in increasing the 2,4-dinitrophenol removal from the sandy soil.

The treated clay soil chamber appeared to have an initial 50% loss of 2,4-dinitrophenol concentration in the upper layer during the first 12 days. After day 12 the upper layer 2,4-dinitrophenol concentrations were relatively stable between 500-1000 ppm. The 2,4-dinitrophenol concentration in the upper layer clay soil control chamber were near 2000 ppm on day 12 and gradually decreased to 1000 ppm by day 62. After the initial treatment of the microorganisms, the 2,4-dinitrophenol concentrations in the treated clay soil chamber were reduced by at least 1000 ppm. However, further reductions in the 2,4-dinitrophenol levels did not occur.

LAND RESTORATION TECHNIQUE IV - CADMIUM NITRATE AND LEAD NITRATE SPILL

Soil pH

The soil pH levels are presented in Tables H-1 and H-2 of Appendix H. The average pH levels for the organic, sandy, and clay soils were 6.9, 6.0 and 6.6, respectively, for the cadmium uptake experiment and 6.9, 5.8 and 6.7, respectively, for the lead uptake experiment.

Soil Metal Levels

Initial and final cadmium and lead soil concentrations are presented in Table 55. Variations in metal concentrations between soils were primarily due to soil density. Soil cadmium concentrations decreased during the experiment in all the chelated soil chambers and in the pH adjusted sandy soil chambers which contained lettuce and chard. Soil lead concentrations decreased during the experiment in the treated organic and sandy soil chambers.

Plant Uptake of Metals

The lead levels in the selected plants are presented in Table 56. After the first collection of plant samples, on day 30, the high lead levels were found in both the acidic soil and acidic soil plus EDTA chamber plants. The controls had very low levels of lead. The rye grass had levels of 135 and 85 ppm from the organic and sandy chelated soil chambers. The Kentucky fescue grass had lead levels of 129 and 88 ppm from the sandy and clay (pH adjusted only) soil chambers. Stress of the plants was noted in sandy and clay soil chambers. Shortly after emergence, the beet plants died. Swiss chard was then planted to replace the beets on day 22.

TABLE 55. AVERAGE SOIL CONCENTRATIONS OF CADMIUM AND LEAD

Soil Type	Chamber Treatment	Cadmium (ppm, dry weight)				Lead (ppm, dry weight)			
		Initial		Final		Initial		Final	
		0-5 cm	5-15 cm	0-5 cm	5-15 cm	0-5 cm	5-15 cm	0-5 cm	5-15 cm
Organic	Control	3	3	3	3	4	4	4	4
	Metal/Lettuce, Beets	165	145	151	100	321	238	286	85
	Metal/Chelated	173	133	58	29	225	255	208	104
	Metal/rye, Kentucky fescue grass	165	179	158	10	261	116	156	42
Sandy	Control	3	3	3	3	4	5	5	4
	Metal/Lettuce, Beets	86	34	31	14	516	282	201	110
	Metal/Chelated	108	110	51	55	267	60	148	69
	Metal/rye, Kentucky fescue grass	58	17	83	43	287	47	123	-
Clay	Control	4	3	4	4	4	4	4	5
	Metal/Lettuce, Beets	45	64	47	8	169	139	305	96
	Metal/Chelated	90	37	20	17	105	137	185	100
	Metal/rye, Kentucky fescue grass	52	60	39	34	210	164	262	73

TABLE 56. LEAD LEVELS IN PLANTS AS A FUNCTION OF SOIL TYPE AND TREATMENT

Day	Plant Type	Soil Type	Soil Treatment	Lead Levels; ppm Dry Weight
30	rye grass	organic	control	5.7
30	rye grass	organic	pH	119
30	rye grass	organic	chelated + pH	135
30	Kentucky fescue grass	organic	control	10.0
30	Kentucky fescue grass	organic	pH	13
30	rye grass	sandy	control	40
30	rye grass	sandy	pH	90
30	rye grass	sandy	chelated + pH	85
30	Kentucky fescue grass	sandy	control	14
30	Kentucky fescue grass	sandy	pH	129
30	Kentucky fescue grass	sandy	chelated + pH	115
30	rye grass	clay	control	<1
30	rye grass	clay	pH	35
30	Kentucky fescue grass	clay	pH	88
43	rye grass	organic	control	<1
43	Kentucky fescue grass	organic	control	5
43	Kentucky fescue grass	organic	pH	143
70	rye grass	organic	chelated + pH	33
70	rye + weed contaminant	organic	control	10
70	lettuce	organic	chelated + pH	15
70	weed + contaminant	organic	chelated + pH	18
70	Kentucky fescue grass	organic	control	6
70	Kentucky fescue grass	organic	chelated + pH	18
70	rye grass	sandy	control	15
70	rye grass	sandy	pH	9
70	weed contaminant	sandy	pH	15
70	weed contaminant	sandy	chelated + pH	38
70	rye grass	clay	chelated + pH	145
70	Kentucky fescue grass	clay	control	7.9
70	weed contaminant	clay	pH	55
103	rye grass	organic	control	6
103	rye grass	organic	chelated + pH	23
103	lettuce	organic	control	<1
103	lettuce	organic	pH	8
103	lettuce	organic	chelated + pH	8
103	Kentucky fescue grass	organic	pH	5
103	weed contaminant	organic	control	4
103	weed contaminant	organic	chelated + pH	8
103	rye grass	sandy	control	<1
103	rye grass	sandy	pH	15
103	rye grass	sandy	chelated + pH	15
103	Kentucky fescue grass	sandy	control	2.5
103	rye grass	clay	control	17
103	rye grass	clay	pH	15
103	rye grass	clay	chelated + pH	28
103	Kentucky fescue grass	clay	pH	55
103	weed contaminant	clay	control	<1

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 287)
TYPING GUIDE SHEET

TABLE 57. CADMIUM LEVELS IN PLANTS AND SOIL TREATMENT

Day	Plant Type	Soil Type	Soil Treatment	Cadmium Levels; ppm Dry Weight
30	rye grass	organic	control	9.5
30	rye grass	organic	pH	143
30	rye grass	organic	chelated + pH	321
30	Kentucky fescue grass	organic	control	<.5
30	Kentucky fescue grass	organic	chelated + pH	273
30	rye grass	sandy	control	2.5
30	rye grass	sandy	pH	204
30	rye grass	sandy	chelated + pH	900
30	Kentucky fescue grass	sandy	pH	84
30	Kentucky fescue grass	sandy	chelated + pH	486
43	rye grass	organic	control	2.1
43	Kentucky fescue grass	organic	control	<.5
43	Kentucky fescue grass	organic	pH	12.8
43	Kentucky fescue grass	sandy	pH	146
70	rye grass	organic	control	<.5
70	rye grass	organic	pH	41
70	weed contaminant	organic	control	4.3
70	weed contaminant	organic	chelated + pH	75
70	rye grass	sandy	pH	125
70	rye grass	sandy	chelated + pH	120
70	lettuce	sandy	pH	350
70	weed contaminant	sandy	pH	22
70	weed contaminant	sandy	chelated + pH	75
70	rye grass	clay	pH	56
70	rye grass	clay	chelated + pH	188
70	weed contaminant	clay	control	< .5
70	weed contaminant	clay	pH	74
104	rye grass	organic	control	2
104	rye grass	organic	pH	20
104	rye grass	organic	chelated + pH	39
104	lettuce	organic	pH	40
104	lettuce	organic	chelated + pH	123
104	swiss chard	organic	chelated + pH	25
104	Kentucky fescue grass	organic	control	1
104	weed contaminant	organic	control	< .5
104	weed contaminant	organic	pH	9.8
104	weed contaminant	organic	chelated + pH	37
104	weed contaminant	organic	chelated + pH	44
104	rye grass	sandy	control	< .5
104	rye grass	sandy	chelated + pH	79
104	swiss chard	sandy	chelated + Ph	37

(continued)

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 337)
TYPING GUIDE SHEET

BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD: BEGIN SECTIONS HERE

TABLE 57. (CONTINUED)

Day	Plant Type	Soil Type	Soil Treatment	Cadmium Levels; ppm Dry Weight
104	Kentucky fescue grass	sandy	control	< .5
104	Kentucky fescue grass	sandy	chelated + pH	38
104	weed contaminant	sandy	control	1.3
104	weed contaminant	sandy	chelated + pH	53
104	rye grass	clay	control	1.7
104	rye grass	clay	pH	49
104	weed contaminant	clay	control	1.0
104	weed contaminant	clay	pH	45
104	weed contaminant	clay	chelated + pH	47

6-1/2"
9-1/8"
BEGIN LAST LINE OF TEXT
3/8"
BOTTOM OF IMAGE AREA: OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS

PAGE NUMBER
EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN: EPA FORM 287)
☆ U.S. GOVERNMENT PRINTING OFFICE: 1980-660-639
TYPING GUIDE SHEET

Plant samplings after day 30 usually had lead levels less than 100 ppm. Two exceptions were the rye grass on day 70 from the chelated clay soil which had lead levels of 145 ppm. Also the Kentucky fescue grass on day 43 from the acidic organic soil had lead levels of 143 ppm. The lettuce did not accumulate lead to levels greater than 10 ppm.

The data on the uptake of cadmium by plants are presented in Table 57. Three collections of the grasses and one or two collections of the lettuce or chard were conducted during the study.

The highest cadmium uptake was observed on day 30 in the chambers receiving the chelating agent disodium EDTA. The rye grass had cadmium levels from the organic and sandy soils of 321 and 900 ppm. The Kentucky fescue grass had cadmium levels from the organic and sandy soils of 273 and 486 ppm, respectively. The lettuce, sampled on days 70 and 104, had cadmium levels of 350 and 123 ppm, respectively, from the sandy and organic soil chambers. The swiss chard sampled day 104 had levels of 37 ppm in the chelated sandy soil chamber.

Discussion of Results

Overall, the plants grown in the chelated soils had higher metal levels. Chelating agents increase the plant uptake of metals by solubilizing the metals and increasing their diffusion to root surfaces (Wallace *et al.*, 1978). The disodium EDTA was added to the soil only once in the early part of the experiment. This chemical is biodegradable and was probably removed from the soil. It appears that repeated applications of EDTA or other chelating agents would make the metals more available to the plants on a continuous basis and thus increase the removal of the metals from the soil. For cadmium, EDTA significantly increased the uptake of the metal by the vegetation. The results were not as dramatic for lead.

The reduction of cadmium concentrations in the chelated soils during the experiment was due to the uptake of cadmium by the plants and leaching of the metal from the soil. The cadmium concentrations in the chelated sandy soil chamber decreased by about 50%. The grasses sampled from the chamber during the first 30 days accounted for 1-2% of the metal loss. If the grass had been planted in the entire chamber and complete harvesting had been conducted, the amount of metal removed would have been greater. However, at least several harvests would need to be conducted before significant losses of cadmium from the soil would occur.

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 287)
TYPING GUIDE SHEET

SECTION 9

EVALUATION OF THE LAND RESTORATION TECHNIQUES

The results of the laboratory studies on the four land restoration techniques were evaluated for their applicability to real-life spill situations by the following criteria:

- applicability to and effectiveness for a wide variety of spilled hazardous materials, soil conditions and weather conditions
- degree of acceleration of recovery rates
- cost of treatment

The enhancement of in situ microbial degradation by indigenous microorganisms surviving the spill was studied in Technique I. To enhance the microbial degradation, essential nutrients are added to the soil with or without plowing for aeration. This technique offers a low cost method for accelerating the restoration of spill damaged lands. However, it is only effective for water soluble, low microbial toxicity and easily biodegradable chemicals such as ammonium acetate. The microbial population can not adapt rapidly enough to degrade volatile compounds of low water solubility such as monochlorobenzene. Water insoluble compounds, e.g., Ethion, also can not be degraded to any extent by this method. The chemical must come in contact with the cell to be degraded (Stanier, et al., 1963). The technique is applicable to a wide variety of soil conditions when the proper nutrients are supplied. Weather conditions are a major factor in the effectiveness of this land restoration technique. Since microbial degradation proceeds most rapidly under warm, moist conditions, Technique I would be of little value in cold (<0°C) weather.

In Technique II, a mixed culture of microorganisms obtained from primary sewage effluent was applied to the spill-damaged land with and without additional nutrients. This technique is a low-cost, effective method of accelerating the removal of water soluble, biodegradable organics from the soil. The data obtained during the experimental phase of the programs indicate that this method can accelerate the removal of the spilled chemical from most soil types. In general, organic and sandy soils yield the highest rate of removal. Drawbacks to Technique II are cold weather and the fact that the chemical must be water soluble or made water soluble by an acid/base reaction.

Technique III is a promising approach for the future even though only minor success was obtained in this program. This approach applies microbial

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 287)
TYPING GUIDE SHEET

degradation methods to environmentally persistent compounds such as the polychlorinated organics and organic nitro compounds. The method used in the experimental phase of this program was to adapt a pure or mixed culture of microbes to use the chemical as the sole carbon source through a series of subculturing techniques. This procedure can be taken one step further. Instead of an adaptation/mutation procedure, the organisms can be genetically engineered to contain the proper enzyme systems to degrade particular chemicals. Both the adapted/mutant and genetic engineering approaches require a stock pile of microorganisms for use in a spill situation. In addition, significantly more research is needed in this area to develop the organisms for degrading the chlorinated organics. The limited water solubility of these compounds is still a problem. The organisms must also possess the ability to concentrate these lipid soluble-water insoluble chemicals so that sufficient quantities are available to them for degradation.

To summarize, Technique III, has four drawbacks; 1) more research is needed to develop the microorganisms, 2) the cost of spill clean-up is higher than for Techniques I or II, 3) the technique will not work in temperatures consistently below 0°C, and 4) soil nutrient conditions must be maintained in the proper balance. However, it is still less expensive than removal of the soil or doing nothing and permitting the chemical to remain in the soil.

The selective absorption of chemicals by harvestable plants (Technique IV) is useful primarily for metals, however, it is also useful for removing some organics from the soils, e.g., Ethion. The soil conditions must be optimized to favor uptake of the chemical by the plants. In the case of metals, acidic soils and chelating agents greatly improve the uptake. The method can accelerate the removal of hazardous chemicals from the soil. However, it has some limitations; 1) the plants cannot grow in the presence of very high concentrations of certain metals and chemicals, 2) the technique is only effective in removing the chemical during the growing season, 3) the soil must be continuously monitored and treated to optimize plant uptake of the chemical, 4) the vegetation must be harvested on a regular basis and either landfilled in a secure landfill or otherwise properly disposed of and 5) animals must not be allowed to forage on the vegetation.

All these in situ techniques are slow (they will not restore the land in a few days or weeks), however, they are less expensive than most of the methods that have been applied to land restoration in the past. For near future applicability, Techniques II and IV have the greatest potential. Technique I has very limited use and Technique III is still in the early research stages.

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 287)
TYPING GUIDE SHEET

BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD: BEGIN SECTIONS HERE

SECTION 10

FIELD DEMONSTRATION TEST DESIGN

For a land restoration method to be of value, it must be viable under real-life spill and environmental conditions. This section presents a test plan for demonstration of two land restoration techniques on three chemicals under actual environmental conditions - microbial degradation and vegetative uptake of metals. The choice of techniques to be evaluated in the field demonstration was based on the results of the laboratory studies. The test plan, as presented is based on simulated spills of the hazardous materials. However, an actual spill could also be evaluated, if desired. The test plan is composed of four tasks. The experimental procedure to be used in the tasks are discussed in the following sections.

SITE SELECTION AND PRETEST PREPARATION - TASK I

Task I - Pretest Preparation

During Task I, the sites for the simulated spills to be conducted in Tasks II, III and IV will be selected. These spill sites will be located at ARC's Gainesville, Virginia facility. Two sites, representing a high textured (sandy-sandy loam) soil and a medium to heavy textured (loam-clay loam) soil, will be chosen to evaluate soil effects on restoration techniques used to decontaminate land. The following criteria will be used in choosing spill sites:

- sufficient land area to accomodate plots for Tasks II, III and IV
- relatively uniform slope (less than 2% slope)
- homogeneity of soil type and texture
- minimum possibility of hazardous materials being transported from the plot area by water movement through the soil either horizontally or through percolation to the water table
- preferably soil pH in the range of 6.0 to 7.0
- moderately high soil fertility levels

Site selection will be based on information in the soil survey manual for Prince William County and on-site inspection. If suitable sites are not available, soils may be altered (i.e., lime and/or fertilizer addition) or an alternative

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA: OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 287)
U.S. GOVERNMENT PRINTING OFFICE
TYPING GUIDE SHEET

area may be located. In addition, if the potential exists for the chemicals to leach into ground water, a plastic liner will be used underneath the treated soil.

Separate plots for Tasks II, III and IV will be constructed at each soil type-site. As it is not known if the soil type will vary in one or two dimensions, *the plot design will be set up as a Latin square. This design will allow for* blocking in either or both directions across plots as needed to remove variation due to soil. If the soil does not vary appreciably in the plots, the results may be analyzed as a completely random experiment.

The plot design is illustrated in Figure 56. Three treatments (unamended, amended with hazardous chemical(s), and amended with hazardous chemicals and then receiving a reclamation treatment) with three replications are included in each set of plots. For each plot, a 2.1x2.1 m (7x7 foot) area will be sectioned off with either plastic or aluminum edging. A 1.5x1.5 m (5x5 foot) area in each plot will receive the appropriate treatment. The borders around the treated area will be grassed, and along with the edging will serve to prevent cross contamination of plots by horizontal movement of soil and water flow.

Soil parameters to be measured prior to initiation of Tasks II through IV are:

- CEC
- soil pH
- soil bacteria
- soil fungi
- soil actinomycetes
- total nitrogen
- potassium
- phosphorus
- soil texture
- soil metal levels

Techniques for these determinations will be as described in Methods of Soil Analysis, American Society of Agronomy Monograph No. 9 (1965). This task will require one month to complete.

LAND RESTORATION AFTER A FORMALDEHYDE SPILL - TASK II

The microbial degradation of formaldehyde in the soil will be evaluated in this task. Plots in the two sites chosen in Task I will receive the following treatments:

- untreated
- formaldehyde addition
- formaldehyde addition followed by addition of mixed microbial culture

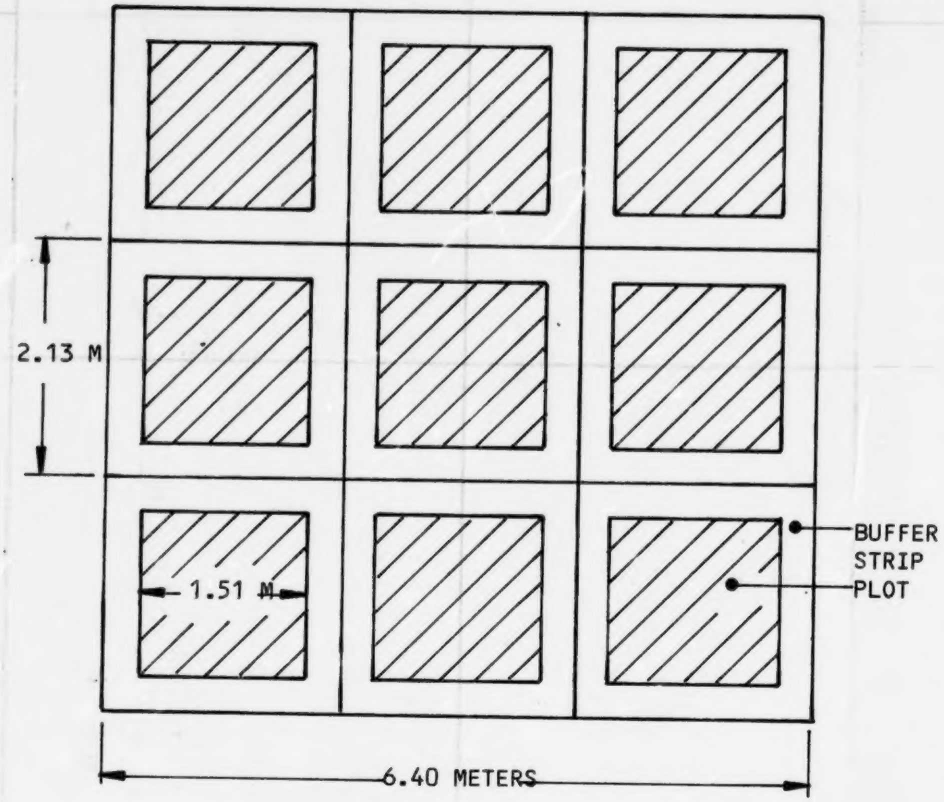

2.13 M
1.51 M
6.40 METERS
BUFFER STRIP
PLOT

Figure 56. Test Plot Design.

Formaldehyde at the rate of 0.11 g/cm^2 (6 liters/plot) will be applied uniformly on the appropriate plots. After 48 hours, 11.5 liters of a mixed microbial culture, isolated from primary sewage effluent, will be applied to three of the plots containing the formaldehyde. The microorganisms will be grown up in a nutrient salts solution containing 5000 ppm formaldehyde. The organisms which can utilize formaldehyde will be selected.

Plots will be sampled at 24 and 48 hours, then every third day for three weeks, and then weekly for the next 7 weeks. Four 2.5 cm core samples will be removed from each plot. The cores will be divided into 0-15.24 cm, 15.24-30.48 cm, 30.48-60.95 cm, and 60.95-91.44 cm segments. Pooled sub-samples from each plot will be used for chemical and microbial analyses. Samples will be stored in polyethylene bags and returned to the laboratory within two hours for immediate formaldehyde and microbiological analyses.

Formaldehyde will be extracted from the moist soil by shaking approximately 25 grams of soil with 50 ml of distilled water. The mixture will be allowed to stand for 1 hour, then decanted, and the supernatent centrifuged at 3200 rpm. This procedure will be repeated and the combined supernatants will then be put into GC autosampler vials. The samples will be quantified using a Varian 3700 GC with autosampler and flame ionization detector under the following conditions:

- injection port temperature: 290°C
- oven temperature: 135°C
- carrier gas: N_2 at a flow rate of 30 ml/min
- Column: Porapak T

The peak areas will be integrated with a Varian CDS 111. The results will be compared to a standard curve obtained with known concentrations of formaldehyde in water.

A one gram sample of moist soil will be serially diluted with sterile water and plated for total bacteria, fungi and actinomycete determinations according to methods described in Methods of Soil Analysis, ASA Monograph No. 9 (1966). A third subsample of the soil will be used to determine soil moisture (dried 24 hours at 106°C). The remaining soil will be air dried and pH determined on a 1:1 soil:water slurry using a pH meter and combination glass-calomel electrode.

The following parameters will be evaluated using analysis of variance (ANOVA):

- formaldehyde content
- soil actinomycetes
- soil bacteria
- soil pH

- soil fungi

The degree of soil variability in the plot areas is not presently known. If soil type is found to vary in two directions, a latin square model may be used to test for treatment differences within each sampling. However, no valid statistical design will allow for testing differences between sampling times. The ANOVA table for the latin square design would be as shown in Table 58.

It is not expected that any interactions between Rows, Columns, and Treatments will exist. Thus, it will be assumed that all interactions are not significant. If for most sampling items, variation in either Rows or Columns is not significant, it will be assumed that blocking in two directions is not needed and all data will be analyzed as a factorial experiment with blocking. The ANOVA table for this design would be as shown in Table 59.

If blocking does not significantly reduce the error term, the data will be analyzed in a two-way analysis of variance. Table 60 illustrates how data is handled by this model.

Ideally the plot sites will be selected so as to reduce soil variability and thus eliminate the need for blocking. It is expected that the completely random two-way classification design will be used.

Prior to calculations for the analysis of variance, the data will be analyzed for homogeneity of variance using the Burr-Foster Q test (Anderson and McLean, 1974). It is probable that a log transformation will be necessary to correct for non-homogeneity of variance for several factors, notably the microbiological determinations.

TABLE 58. ANOVA: LATIN SQUARE DESIGN

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F Ratio
Rows (r)	2	SSr	$SS_r/2=MS_r$	MS_r/s^2
Column (c)	2	SS_c	$SS_c/2=MS_c$	MS_c/s^2
Treatments (t)	2	SS_t	$SS_t/2=MS_t$	MS_t/s^2
Error	2	SS_e	$SS_e/1=s^2$	
Total	8	SS_{total}		

BEGIN FIRST LINE OF TEXT HERE
TYPING GUIDE SHEET
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD BEGIN SECTIONS HERE

TABLE 59. ANOVA: FACTORIAL EXPERIMENT WITH BLOCKING

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F Ratio
Blocks (b) (either row or columns)	2	SS_b	$SS_b/2=MS_b$	MS_b/s^2
Treatments (t)	2	SS_t	$SS_t/2=MS_t$	MS_t/s^2
Sampling Times (s)	15	SS_s	$SS_s/5=MS_s$	MS_s/s^2
Interaction of TXS	30	SS_{txs}	$SS_{txs}/30=MS_{txs}$	MS_{txs}/s^2
Error	94	SS_e	$SS_e/94=s^2$	
Total	143	SS_{total}		

TABLE 60. ANOVA: TWO-WAY ANALYSIS

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F Ratio
Treatment (t)	2	SS_t	$SS_t/2=MS_t$	MS_t/s^2
Sampling time (s)	15	SS_s	$SS_s/15=MS_s$	MS_s/s^2
Interaction of TXS	30	SS_{txs}	$SS_{txs}/30=MS_{txs}$	MS_{txs}/s^2
Error	96	SS_e	$SS_e/96=s^2$	
Total	143	SS_{total}		

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

All statistical testing will be performed at the 5% level of probability. Where significance is indicated by the ANOVA, the Student-Newman-Keuls multiple range test will be employed to compare means. The means of parameters analyzed in log form will be presented as geometric means. All other means will be presented as arithmetic means. Task II will take three months to complete.

LAND RESTORATION AFTER AN ANILINE SPILL - TASK III

An aniline spill will be simulated as described for the formaldehyde spill in Task II. The treatments will be as described in Task II except aniline will be applied at 0.27 g/cm^2 (6 liters/plot) and the reclamation treatment will consist of adding 11.5 liters of adapted sewage effluent previously incubated in the presence of 5000 ppm aniline, with additions of yeast extract and nutrient salts to promote microbial growth.

The plots will be sampled at 24 and 48 hours, and then weekly for the next 15 weeks. Sampling procedures will be as stated in the Task II experimental description.

Aniline will be determined in the soil by solvent extraction and gas chromatograph quantification. Two grams of moist soil will be shaken with 0.5 ml of 24% solution NaOH in methanol and 4.0 ml of 50:50 methanol-methylene chloride mixture. This mixture will then be centrifuged and decanted. An additional 4.0 ml of methylene chloride will be added to the soil, shaken, centrifuged and decanted. The combined liquid will be shaken with 6.0 ml of distilled water and then centrifuged. A subsample of the methylene chloride layer will be used for gas chromatographic analysis. The gas chromatograph will be a Varian 3700 GC with a flame ionization detector operated under the following conditions:

- injection port temperature: 300°C
- oven temperatures: 140°C for 4 minutes; increased temperature 20°C/minute for 2 minutes; 180°C for 3 minutes
- detector temperature: 300°C
- carrier gas: N_2 at a flow rate of 30 cc/min
- column: 1.82M x 0.2 mm ID 10% Carbowax 20 m/2% KOH on Chromosorb WAW

The peak areas will be integrated with a Varian CDS 111. The results will be compared to a standard curve obtained with known concentrations of aniline in water.

Microbiological determinations, pH and percent moisture will also be determined as described in Task II. The statistical treatment of the data will be as stated for Task II.

EPA-287 (Cin.)
(4-76)

BEGIN FIRST LINE OF TEXT HERE
TYPING GUIDE SHEET
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD, BEGIN SECTION HERE

LAND RESTORATION AFTER A SPILL OF CADMIUM NITRATE - TASK IV

The feasibility of renovating Cd contaminated soil by vegetative uptake and removal will be examined in Task IV. Plots on both soil types chosen in Task I will receive the following treatments:

- untreated
- Cd addition
- Cd addition followed by treatment with EDTA

Cadmium as $Cd(NO_3)_2$ at the rate of 1.4×10^{-2} g/cm^2 (328 g/plot) will be applied uniformly in a dilute solution on the appropriate plots. After a minimum of 30 days, ethylenediaminetetraacetic acid (EDTA) will be applied to three of the Cd treated plots (0.25 ml of 0.1M NaEDTA/cm^2 or 5.8 liters of 0.1M NaEDTA/plot).

Each plot will be divided into three areas for seeding rye grain, swiss chard and perennial rye grass. The EDTA application will be timed to roughly precede seeding by one week.

The rye grain and rye grass will be harvested at maturity. Grain and vegetative tissue will be analyzed separately for the total Cd content. Swiss chard will be harvested 40 days after emergence for total Cd determination. Dry matter of the vegetative growth and grain yield will be measured for all crops.

Soil samples will be collected at planting and harvesting times. Four 2.5 cm core samples will be removed from the soil supporting each crop in every plot. The cores will be separated into 0-15.24 cm and 15.24-30.48 cm segments and total Cd extracted and quantified. Soil pH will be measured as previously described for Task II.

Cadmium determinations for both plant and soil samples are described by Isaac and Kerber (1971). The methods described as Wet Digestion and Acid Dissolution will be used for tissue and soil analyses, respectively. The statistical treatment of the data will be as stated in Task II description.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA, OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-70)

BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD, BEGIN SECTIONS HERE

SECTION 11

OPERATING PROCEDURES FOR RESTORATION OF SPILL-DAMAGED LANDS

The purpose of this section of the report is to provide a guide to aid the on-site spill response coordinator in selecting an appropriate restoration technique for a land area damaged by a spill of a hazardous chemical, sludge, paint or petrochemical wastes. The restoration techniques are to be applied after the clean-up of the major portion of the spilled material. The goals of any land restoration technique are to restore the land to its original condition (or better) and prevent movement of toxic chemicals in the environment. The hazardous chemicals considered in this guide were taken from the hazardous substances list published in the Federal Register, Vol. 43 (49), p. 1047-10474. The chemicals in this list have been compiled as hazardous substances for spills in water. Many of these chemicals are not a major problem when spilled on land except under adverse weather conditions. For example, the ammonium salts which are highly toxic to fish when spilled in waterways, can be used as a nutrient source by plants. In general, non-water soluble solids and many water soluble solids can be sufficiently removed from the land surface during the initial response. Therefore, they do not require extensive land restoration methods.

Applicable land restoration techniques for each of these hazardous materials have been selected based on the known physical, chemical and biological properties of the compound. A detailed search of the literature for all the properties of each chemical was beyond the scope of work. Therefore, the information on the properties of 271 hazardous chemicals were compiled from the information available in reference sources such as the CHRIS list and OHM-TADS. Where sufficient information on a specific chemical was unavailable, scientific judgement was used to predict its fate in the soil environment. The data for the 271 chemicals are presented in Table 61.

Each chemical in the table was classified into four major categories according to its expected fate in the soil environment:

1) NP: non-persistent organics and inorganic salts

2) EP: environmentally persistent organics

3) TM: inorganic and metal organic compounds containing toxic metals

4) TA: inorganic compounds containing toxic anions

The non-persistent category includes biodegradable organic compounds such as acetic acid, biouseable inorganic salts, e.g., ammonium sulfate, and volatile,

BEGIN LAST LINE OF TEXT
3/8"
BOTTOM OF IMAGE AREA, OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS

PAGE NUMBER
EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 287)
☆ U.S. GOVERNMENT PRINTING OFFICE 1980-

TABLE 61. HAZARDOUS CHEMICAL CLASSIFICATION AND APPLICABLE RESTORATION TECHNIQUES

CAS No.	Common Name	Synonyms	Major Environmental Classification	Environmental Properties	Applicable Land Restoration Technique(s)
75070	Acetaldehyde	Ethanal, ethyl aldehyde, acetic aldehyde	NP	s,b,r	II
64197	Acetic acid	Glacial acetic acid, vinegar acid	NP	s,b,r	III,II,VIII
108247	Acetic anhydride	Acetic oxide, acetyl oxide	NP	s,r,b	III,II,VIII
75865	Acetone cyanohydrin	2-methyllactonitrile, alpha-hydroxylsobutyronitrile	NP	s,r,b	II,VIII
506967	Acetyl bromide		NP	s,r,b,u	III,II,VIII
79367	Acetyl chloride		NP	s,r,b,u	III,II,VIII
107028	Acrolein	2-propenal, acrylic aldehyde, acrylaldehyde, acraldehyde	NP	s,b	II
107131	Acrylonitrile	Cyanoethylene, Fumigrain, Ventox, propenenitrite, vinyl cyanide	NP	s,r,b	II,VIII
309002	Aldrin	Octalene, HHDN	EP	i,t(p),r(p)	V,(VII),(II)
107186	Allyl alcohol	2-propen-1-ol, 1-propenol-3, vinyl carbinol	NP	s,b	II
107051	Allyl chloride	3-chloropropene, 3-chloropropylene, Chlorallylene	NP	s,r(slowly),b	II
10043013	Aluminum sulfate	Alum	EP	s,n	I
7664417	Ammonia		NP	s,r,u	III,VIII
631618	Ammonium acetate	Acetic acid ammonium salt	NP	s,u	II,VIII
1863634	Ammonium benzoate		NP	s,u,b	II,VIII
1066337	Ammonium bicarbonate	Acid ammonium carbonate, ammonium hydrogen carbonate	NP	s,u	I,VIII

(continued)

EPA Form 2360-4 (4-80)
(PREVIOUSLY CIN. EPA FO.1M 337)
TYPING GUIDE SHEET

TABLE 61 (CONTINUED)

CAS No.	Common Name	Synonyms	Major Environmental Classification	Environmental Properties	Applicable Land Restoration Technique(s)
7789095	Ammonium bichromate		TM	s,p	V,IV,VI
1341497	Ammonium bifluoride	Acid ammonium fluoride, ammonium hydrogen fluoride	TA	s,u	VIII
10192300	Ammonium bisulfite		NP	s,u	II,VIII
1111780	Ammonium carbamate	Ammonium aminoformate	NP	s,b	II,VIII
506876	**Ammonium carbonate**		ND	s,u	II,VIII
12125029	Ammonium chloride	Ammonium muriate, sal ammoniac, salmiac, Amchlor	NP	s,u	II,VIII
7788989	Ammonium chromate		EP	s,p	IV,V,VI
3012655	Ammonium citrate dibasic	Diammonium citrate, citric acid, diammonium salt	NP	s,b	II,VIII
13826830	Ammonium fluoborate	Ammonium fluoroborate, ammonium borofluoride	EP	s,i,n	VIII
12125018	Ammonium fluoride	Neutral ammonium fluoride	TA	s,u	VIII
1336216	Ammonium hydroxide		NP	s,r,u	III,VIII
6009707	Ammonium oxalate		NP	s,b	II,VIII
5972736	" "				
14258492	" "				
16919190	Ammonium silicofluoride	Ammonium fluosilicate	EP	s,u,n	VIII
7773060	Ammonium sulfamate	Ammate, AMS, ammonium amido-sulfate	NP	s,u	VIII
12135761	Ammonium sulfide		EP	s,n	VIII
10196040	Ammonium sulfite		NP	s,u	VIII
10192300	" "				

(continued)

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 237)
TYPING GUIDE SHEET

TABLE 61 (CONTINUED)

CAS No.	Common Name	Synonyms	Major Environmental Classification	Environmental Properties	Applicable Land Restoration Technique(s)
3164292	Ammonium tartrate	Tartaric acid ammonium salt	NP	s,b	II,VIII
14307438	" "				
1762954	Ammonium thiocyanate	Ammonium rhodanide, ammonium sulfocyanate, ammonium sulfocyanide	NP	s,u	II,VIII
7783188	Ammonium thiosulfate	Ammonium hyposulfite	NP	s,u	II,VIII
628637	Amyl acetate	Amylacetic ester Pear oil Banana oil	NP	s,b	II
62533	Aniline	Aniline oil, phenylamine, aminobenzene, aminophen, kyanol	NP	s,r,b	II,VIII
7647189	**Antimony pentachloride**		TM	s,r,p	V,III,IV
28300745	Antimony potassium tartrate	Tartar emetic, tartrated antimony, tartarized antimony, potassium antimonyl-tartrate	TM	s,u,p	V,(IV)
7789619	Antimony tribromide		TM	s,r,p	V,(IV)
10025919	Antimony trichloride	Butter of antimony	TM	s,r,p	V,(IV)
7783564	Antimony trifluoride	Antimony fluoride	TM	s,r,p	V,(IV)
1303328	Antimony trioxide	Diantimony trioxide, flowers of antimony	TM	i,p	I,(IV)
1303328	Arsenic disulfide	Red arsenic sulfide	TM	r,p	V,(IV)
778431	Arsenic trichloride	Arsenic chloride, arsenious chloride, arsenious chloride, butter of arsenic	TM	s,p	V,(IV)
1327533	Arsenic trioxide	Arsenious acid, arsenious oxide, white arsenic	TM	i,p	V,(IV)

(continued)

TABLE 61 (CONTINUED)

CAS No.	Common Name	Synonyms	Major Environmental Classification	Environmental Properties	Applicable Land Restoration Technique(s)
1303339	Arsenic trisulfide	Arsenious sulfide, yellow arsenic sulfide	TM	i,p	V,(IV)
542621	Barium cyanide		TM	s,p	V,(IV)
71432	Benzen	Cyclohexatriene, benzol	NP	i,v,b	I
65850	Benzoic acid	Benzenecarboxylic acid, phenylformic acid, dracylic acid	NP	s,b	II
100470	Benzonitrile	Phenyl cyanide, cyanobenzene	NP	s,r,b	II,VI
98884	Benzoyl chloride	Benzenecarbonyl chloride	NP	s,r,b	III,II
100447	Benzyl chloride		NP	i,v,r,b	II
7787475	Beryllium chloride		TM	s,p	V,(IV)
7787497	Beryllium fluoride		TM	s,p	V,(IV)
7787555	Beryllium nitrate		TM	s,p	V,(IV)
13597994	" "		TM	s,p	V,(IV)
123864	Butyl acetate	Acetic acid butyl ester	NP	s,v,r,b	II
109739	Butylamine	1-aminobutane	NP	s,r,b	III,II,VIII
107926	Butyric acid	Butanoic acid, ethyl-acetic acid	NP	s,b	III,II,VIII
543908	Cadmium acetate		TM	s,p	V,IV
7789426	Cadmium bromide		TM	s,p	V,IV
10108642	Cadmium chloride				

(continued)

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 287)
TYPING GUIDE SHEET

TABLE 61 (CONTINUED)

CAS No.	Common Name	Synonyms	Major Environmental Classification	Environmental Properties	Applicable Land Restoration Technique(s)
7778441	Calcium arsenate	Tricalcium orthoarsenate	TM	i,p	V,IV
52740166	Calcium arsenite		TM	i,p	V,IV
75207	Calcium carbide	Carbide, acetylenogen	NP	s,r,u	III
13765190	Calcium chromate	Calcium chrome yellow, geblin, yellow ultramarine	TA	s,r,p	I
592018	Calcium cyanide		TA	s,b,u	III,VIII
26264062	Calcium dodecylbenzenesulfonate		NP	s,b,u	I
1305620	Calcium hydroxide	Lime, hydrated slaked lime, calcium hydrate	NP	s,r,u	III
7778534	Calcium hypochlorite		NP	s,r,u	III
1305788	Calcium oxide	Lime, quicklime	NP	s,r,u	III
133062	Captan	Orthocide-406, SR-406, Vancide-89	NP	s,r,b	III,II
63252	Carbaryl	Sevin	NP	s,r,b	II
75150	Carbon disulfide	Carbon bisulfide, dithiocarbonic anhydride	NP	s,r,u	I
57749	Chlordane	Toxichlor, chlorodan	EP	i,r,p	V,VII
75003	Chlorine		NP	s,r,u	III,VIII
108907	Chlorobenzene	Monochlorobenzen, benzen chloride	NP	i,v,b	II
67663	Chloroform	Trichloromethane	NP	i,v,r,b	I
2921882	Chlorpyrifos	Dursban	NP	s,r,b	II
7790945	Chlorosulfonic acid	Sulfuric chlorohydrin	NP	s,r,u	III,VIII
1066304	Chromic acetate		TM	s,r,p	V,IV

(continued)

TABLE 61 (CONTINUED)

CAS No.	Common Name	Synonyms	Major Environmental Classification	Environmental Properties	Applicable Land Restoration Technique(s)
11115745	Chromic acid	Chromic anhydride, chromium trioxide	TM	s,r,p	V,IV
10101538	**Chromic sulfate**		TM	s,r,p	V,IV
10049055	Chromous chloride		TM	s,r,p	V,(IV)
7789437	Cobaltous bromide	Cobalt bromide	TM	s,r,p	V,(IV)
544183	Cobaltous formate	Cobalt formate	TM	s,r,p	V,(IV)
14017415	Cobaltous sulfamate	Cobalt sulfamate	TM	s,r,p	V,(IV)
56724	Coumaphos	Co-Ral	NP	i,r,b	II
1319773	Cresol	Cresylic acid Hydroxytoluene	NP	s,b	III,II,VIII
142712	Cupric acetate	Copper acetate, crystalized verdigris	TM	s,r,p	IV
12002038	Cupric acetoarsenite	Copper acetoarsenite, copper acetate arsenite, Paris green	TM	i,p	IV
7447394	Cupric chloride	Copper chloride	TM	s,r,p	IV
3251238	Cupric nitrate	Copper nitrate	TM	s,r,p	IV
5893663	Cupric oxalate	Copper oxalate	TM	s,r,p	IV
7758987	Cupric sulfate	Copper sulfate	TM	s,r,p	IV
10308297	Cupric sulfate, ammoniated	Ammoniated copper sulfate	TM	s,r,p	IV
815827	Cupric tartrate	Copper tartrate	TM	s,r,p	IV
506774	Cyanogen chloride		NP	s,v,r	III,VIII
110827	Cyclohexane	Hexahydrobenzene, hexamethylene, hexanaphthene	NP	i,v,r,b	I

(continued)

BEGIN FIRST LINE OF TEXT HERE
DROPPED HEAD: BEGIN SECTIONS HERE
CENTER OF PAGE
TOP OF IMAGE AREA
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
PAGE NUMBER
EPA Form 2350-4 (4-30)
TYPING GUIDE SHEET

TABLE 61 (CONTINUED)

CAS No.	Common Name	Synonyms	Major Environmental Classification	Environmental Properties	Applicable Land Restoration Technique(s)
94757	2,4-D acid	2,4-dichlorophenoxyacetic acid	NP	s,b	II
94111	2,4-D ester	2,4-dichlorophenoxyacetic acid ester	NP	i,b	II
94791	"				
94804	"				
1320189	"				
1928387	"				
1928616	"				
1929733	"				
2971382	"				
25168267	"				
53467111	"				
50293	DDT	P,p-DDT	EP	i,t,p,r	VII,V
333415	Diazinon	Dipofene, Diazitol, Basudin Spectracide	NP	i,b,r	II
1918009	Dicamba	2-methoxy-3,6-dichlorobenzoic acid	NP	s,b	II
1194656	Dichlobenil	2,6-dichlorobenzonitrile, 2,6-DBN	NP	i,b	II
117806	Dichlone	Phygon, dichloronaphthoquinone	EP	i,p	V,VI,VII
75990	2,2-Dichloropropionic acid	Dalapon	EP	s,n	V,II,VII
62737	Dichlorvos	2,2-dichlorovinyl dimethyl phosphate, Vapona	NP	s,r,b	II,III
60571	Dieldrin	Alvit	EP	i,p	V,VII
109897	Diethylamine		NP	s,b	I
124403	Dimethylamine		NP	s,b	I
25154545	Dinitrobenzene (mixed)	Dinitrobenzol	EP	s,t,p	V,II,VI

(continued)

TABLE 61 (CONTINUED)

CAS No.	Common Name	Synonyms	Major Environmental Classification	Environmental Properties	Applicable Land Restoration Technique(s)
51285 (2,4-)	Dinitrophenol	Aldifen	EP	s,t,p	V,II,VI
85007 2764729	Diquat	Aquacide Dextrone, Reglone, Diquat dibromide	EP	s,p	V,II,IV
298044	Disulfoton	Di-syston	EP	s,p,b	II,VI
330541	Diuron	DCMU, DMU	EP	i,t,p	V,II
27176870	Dodecylbenzenesulfonic acid		NP	s,b	III,II,VIII
115297	Endosulfan	Thiodan	EP	i,p	V
72208	Endrin	Mendrin, Compound 269	EP	i,p	V,VII
563122	Ethion	Nialate, ethyl methylene, phosphorodithloate	EP	s,p	II,VI,IV
100414	Ethylbenzene	Phenylethane	NP	i,b,v	I
107153	**Ethylenediamine**	**1,2-diaminoethane**	NP	s,b	III,II,VIII
60004	Ethylenediaminetetra-acetic acid (EDTA)	Edetic acid, Havidote, (ethylenedinitrilo)-tetra-acetic acid	NP	s,b	III,II,VIII
1185575	Ferric ammonium citrate	Ammonium ferric citrate	EP	s,b,u,n	III,IV
2944674 55488874	Ferric ammonium oxalate	Ammonium ferric oxalate	EP	s,b,u,n	III,IV
7705080	Ferric chloride	Flores martis, iron tri-chloride	EP	s,u,n	III,IV
7783508	Ferric fluoride		TA	s,u,n	III,IV
10421484	Ferric nitrate	Iron nitrate	EP	s,u,n	III,IV

(continued)

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 287)
TYPING GUIDE SHEET

TABLE 61 (CONTINUED)

CAS No.	Common Name	Synonyms	Major Environmental Classification	Environmental Properties	Applicable Land Restoration Technique(s)
10028225	Ferric sulfate	Ferric persulfate, ferric sesquisulfate, ferric tersulfate	EP	s,u,n	III,IV
10045093	Ferrous ammonium sulfate	Mohr's salt, iron ammonium sulfate	EP	s,u,n	III,IV
7758943	Ferrous chloride	Iron chloride, iron dichloride iron protochloride	EP	s,u,n	III,IV
7720787 7782630	Ferrous sulfate	Green vitrol Iron vitrol, iron sulfate, iron protosulfate	EP	s,u,n	III,IV
50000	Formaldehyde	Methyl aldehyde, methanol, formalin	NP	s,b	II
64186	Formic acid	Methanoic acid	NP	s,b	III,II
110178	Fumaric acid	Trans-butenedioic acid, trans-1,2-ethylenedicarboxylic acid, boletic acid, allomaleic acid	NP	s,b	III,II
98011	Furfural	2-furaldehyde, pyromucic aldehyde	NP	s,b	II
86500	Guthion	Guzathion, azinphos-methyl	NP	s,r,t,b	III,II
76448	Heptachlor	Velsicol-104, Drinox, Heptagran	EP	i,p	V,VII
7647010	Hydrochloric acid	Hydrogen chloride, muriatic acid	NP	s,u	III,VIII
7664393	Hydrofluoric acid	Fluohydric acid	TA	s,u	III,VIII
74908	Hydrogen cyanide	Hydrocyanic acid	TA	s,b	III,II,VIII
78795	Isoprene	2-methyl-1,3-butadiene	NP	i,r,b	II
42504461	Isopropanolamine dodecylbenzenesulfonate		NP	s,b	II

(continued)

TABLE 61 (CONTINUED)

CAS No.	Common name	Synonyms	Major Environmental Classification	Environmental Properties	Applicable Land Restoration Technique(s)
115322	Kelthane	Di(p-chlorophenyl)-trichloromethylcarbinol, DTMC dicofol	EP	i,p	V,VII
301042	Lead acetate	Sugar of lead	TM	s,p	V,IV,III
7784409 7645252 10102484	Lead arsenate		TM	i,p	V,IV,III
7758954	Lead chloride		TM	s,r,p	V,IV,III
13814965	Lead fluoborate	Lead fluoroborate	TM	s,r,p	V,IV,III
7738462	Lead fluoride	Lead difluoride, plumbous flouride	TM	s,r,p	V,IV,III
10101630	Lead iodide		TM	s,r,p	V,IV,III
7428480 1072351 52652592	Lead stearate	Stearic acid lead salt	TM	s,r,p	V,IV,III
7446142	Lead sulfate		TM	i,p	V,IV,III
1314870	Lead sulfide	Galena	TM	i,p	V,IV,III
592870	Lead thiocyanate	Lead sulfocyanate	TM	s,r,p	V,IV,III
58899	Lindane	Gamma-BHC, gamma-benzene hexachloride	EP	i,p	V,VII
14307358	Lithium chromate		TM	s,p	V,IV
121755	Malathion	Phospothion	NP	s,r,b	III,II
110167	Maleic acid	Cis-butenedioic acid, cis-1,2-ethylenedicarboxylic acid, toxilic acid	NP	s,b	III,II,VIII
108316	Maleic anhydride	2,5-furandione, cis/butenedioic anhydride, toxilic anhydride	NP	s,r,b	III,II,VIII

(continued)

TABLE 61. (CONTINUED)

CAS No.	Common Name	Synonyms	Major Environmental Classification	Environmental Properties	Applicable Land Restoration Technique(s)
592041	Mercuric cyanide	Mercury cyanide	TM	s,r,p	III,V,IV
10045940	Mercuric nitrate	Mercury nitrate, mercury pernitrate	TM	s,p	V,IV
7783359	Mercuric sulfate	Mercury sulfate, mercury persulfate	TM	s,r,p	V,IV
592858	Mercuric thiocyanate	Mercury thiocyanate, mercuric sulfocyanate, mercuric sulfocyanide	TM	s,r,p	III,V,IV
7782867 10415755	Mercurous nitrate	Mercury protonitrate	TM	s,r,p	V,IV
72435	Methoxychlor	DMDT, methoxy-DDT	NP	i,b,r	II
74931	Methyl mercaptan	Methanethiol, mercaptomethane, methyl sulfhydrate, thiomethyl alcohol	NP	s,v,u	I
80626	Methyl methacrylate	Methacrylic acid methyl ester, methyl-2-methyl-2-propenoate	NP	s,v,b,r	II
298000	Methyl parathion	Nitrox-80	NP	s,r,b	III,II
7786347	Mevinphos	Phosdrin	NP	s,r	III
315184	Mexacarbate	Zectran	NP	s,b	II
75047	Monoethylamine	Ethylamine, aminoethane	NP	s,v,b	VIII
74895	Monomethylamine	Methylamine, aminomethane	NP	s,v,b	VIII
300765	Naled	Dibrom	NP	s,r,b	III,II
91203	Naphthalene	White tar, tar camphor, naphthalin	NP	i,v,b	II
1338245	Naphthenic acid	Cyclohexanecarboxylic acid, hexahydrobenzoic acid	NP	s,b	III,II

(continued)

TABLE 61 (CONTINUED)

CAS No.	Common Name	Synonyms	Major Environmental Classification	Environmental Properties	Applicable Land Restoration Technique(s)
15699180	Nickel ammonium sulfate	Ammonium nickel sulfate	TM	s,r,p	V,IV
37211055 7718549	Nickel chloride	Nickelous chloride	TM	s,r,p	V,IV
12054487	Nickel hydroxide	Nickelous hydroxide	TM	s,r,p	V,IV
14216752	Nickel nitrate		TM	s,r,p	V,IV
7786814	Nickel sulfate	Nickelous sulfate	TM	s,r,p	V,IV
7697372	Nitric acid	Aqua fortis	NP	s,r,u	III,VIII
98953	Nitrobenzene	Nitrobenzol, oil of mirbane	NP	s,r,b	II,VI
10102440	Nitrogen dioxide	Nitrogen tetraoxide	NP	s,r,u	III,IV
25164556	Nitrophenol (mixed)	Mononitrophenol	NP	s,r,b	III,II
30525894	Paraformaldehyde	Paraform, Formagene, Triformol, polymerized formaldehyde, polyoxymethylene	NP	s,b	II
56382	Parathion	DNTP, Niran	NP	s,r,b	II,IV,VI
87865	Pentachlorophenol	PCP, Penta	EP	s,p	V,II,VII
108952	Phenol	Carbolic acid, phenyl hydroxybenznee, oxybenzene	NP	s,b	III
75445	Phosgene	Diphosgene, carbonyl cloride, chloroformyl chloride	NP	s,r,u	III
7664382	Phosphoric acid	Orthophosphoric acid	EP	s,r,n,u	I
7723140	Phosphorus	Black phosphorus, red phosphorus, white phosphorus, yellow phosphorus	EP	i,r,n,u	III,VI

(continued)

TABLE 61 (CONTINUED)

CAS No.	Common Name	Synonyms	Major Environmental Classification	Environmental Properties	Applicable Land Restoration Technique(s)
10025873	Phosphorus oxychloride	Phosphoryl chloride, phosphorus chloride	EP	s,r,n,u	III
1314803	Phosphorus pentasulfide	Phosphoric sulfide, thiophosphoric anhydride, phosphorus persulfide	EP	s,r,n,u	III
7719122	Phosphorus trichloride	Phosphorus chloride	EP	s,r,n,u	III
1336363	Polychorinated biphenyls	PCB, Aroclor, polychlorinated diphenyls	EP	i,p	V,VII
7784410	Potassium arsenate		TM	s,r,p	V,IV
10124502	Potassium arsenite	Potassium metaarsenite	TM	s,r,p	V,IV
7778509	Potassium bichromate	Potassium dichromate	TM	s,r,p	V,IV
7789006	Potassium chromate		TM	s,r,p	V,IV
151508	**Potassium cyanide**		TA	s,b	II
1310583	Potassium hydroxide	Potassium hydrate, caustic potash, potassa	NP	s,r,u	III
7722647	Potassium permanganate	Chameleon mineral	TM	s,r,p	V,IV
79094	Propionic acid	Propanoic acid, methylacetic acid, ethylformic acid	NP	s,b	III,II,VIII
123626	Propionic anhydride	Propanoic anhydride, methylacetic anhydride	NP	s,r,b	III,II
121299 121211	Pyrethrins	Pyrethrin I Pyrethrin II	NP	s,r,b	III,VI,II
91225	Quinoline	1-benzazine, benzo(b)pyridine, leucoline,chinoleine, leucol	NP	s,r,b	III,II
108463	Resorcinol	Resorcin, 1,3-benzenediol, meta-di-hydroxybenzene	NP	s,v,r,b	III,II
7446084	Selenium oxide	Selenium dioxide	EP	s,v,r	V

(continued)

TABLE 61 (CONTINUED)

CAS No.	Common Name	Synonyms	Major Environmental Classification	Environmental Properties	Applicable Land Restoration Technique(s)
7440235	Sodium	Natrium	NP	s,r,u	III
7631892	Sodium arsenate	Disodium arsenate	TM	s,r,p	V,IV
7784465	Sodium arsenite	Sodium metaarsenite	TM	s,r,p	V,IV
10588019	Sodium bichromate	Sodium dichromate	TM	s,r,p	V,IV
1333831	Sodium bifluoride		TA	s,u	I
7631905	Sodium bisulfite	Sodium acid sulfite, sodium hydrogen sulfite	NP	s,u	I
7775113	Sodium chromate		TM	s,r,p	V, IV
143339	Sodium cyanide		TA	s,b	II
25155300	Sodium dodecylbenzene-sulfonate		NP	s,b	II
7681494	Sodium fluoride	Villiaumite	TA	s,u	I
16721805	Sodium hydrosulfide	Sodium hydrogen sulfide	TA	s,u	I
1310732	Sodium hydroxide	Caustic soda, soda lye, sodium hydrate	NP	s,u	III
7681529 **10022705**	**Sodium hypochlorite**	**Bleach**	**NP**	s,u	III,VI
124414	Sodium methylate	Sodium methoxide	NP	s,b	III
7632000	Sodium nitrite		NP	s,u	IV
7558794 10039324 10028247 10140655	Sodium phosphate, dibasic		EP	s,n	III

(continued)

TABLE 61 (CONTINUED)

CAS No.	Common Name	Synonyms	Major Environmental Classification	Environmental Properties	Applicable Land Restoration Technique(s)
7785844 7601549 10101890 10361894 7758294 10124568	Sodium phosphate, tribasic		EP	s,n	III
10102188 7782823	Sodium selenite		EP	s,p	V,IV
7789062	Strontium chromate		TM	s,r,p	V,IV
57249	Strychnine		NP	s,b	II
100425	Styrene	Vinylbenzene, phenylethylene, styrol, styrolene, cinnamene, cinnamol	NP	s,r,b	II
7664939	Sulfuric acid	Oil of vitriol, oleum	NP	s,r,u	III,VIII
12771083	Sulfur monochloride	Sulfur chloride	NP	s,r,u	III,VIII
93765	2,4,5-T acid	2,4,5-trichlorophenoxyacetic acid	NP	s,b,r	III,II
2545597 93798 61792072 1928478 25168154	2,4,5-T ester	2,4,5-trichlorophenoxyl/acetic esters	NP	i,b,r	III,II
72548	TDE	DDD	EP	i,b,p	II,V
78002	Tetraethyl lead	Lead tetraethyl, TEL	TM	i,r,p	V,IV
107493	Tetraethyl pyrophosphate	TEPP	EP	s,r,n	III
108883	Toluene	Toluol, methylbenzene, phenylmethane, Methacide	NP	s,v,r,b	I
8001352	Toxaphene	Camphechlor	EP	i,r,p	V,VII

(continued)

TABLE 61 (CONTINUED)

CAS No.	Common Name	Synonyms	Major Environmental Classification	Environmental Properties	Applicable Land Restoration Technique(s)
52686	Trichlorfon	Dipterex Dylox	NP	s,r,b	III,II
25167822	Trichlorophenol	Collunosol, Dowicide 2 or 2S, Omal, Phenachlor	EP	s,p	V,II,VII
27323417	Triethanolamine dodecylbenzenesulfonate		NP	s,r,b	III,II
121448	Triethylamine		NP	s,b	III,II,VIII
75503	Trimethylamine	TMA	NP	s,b	III,II,VIII
541093	Uranyl acetate		TM	s,r,p	V,IV
10102064 36478769	Uranyl nitrate		TM	s,r,p	V,IV
1314621	Vanadium pentoxide	Vanadic anhydride, vanadic acid anhydride	TM	s,r,p	V,IV
27774136	Vanadyl sulfate	Vanadic sulfate, vanadium sulfate	TM	s,p	V,IV
108054	Vinyl acetate	Acetic acid ethylene ether	NP	s,b	II
1330207	Xylene (mixed)	Dimethylbenzene Xylol	NP	i,v,b	I
1300716	Xyleneol	Dimethylphenol, hydroxydimethylbenzene	NP	s,b	III,II
557346	Zinc acetate		TM	s,r,p	V,IV
14639975 14639986 52628258	Zinc ammonium chloride		TM	s,r,p	V,IV
1332076	Zinc borate		TM	s,r,p	V,IV
7699458	Zinc bromide		TM	s,r,p	V,IV
3486359	Zinc carbonate		TM	s,r,p	V,IV

(continued)

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN, EPA FORM 337)
TYPING GUIDE SHEET

TABLE 61 (CONTINUED)

CAS No.	Common Name	Synonyms	Major Environmental Classification	Environmental Properties	Applicable Land Restoration Technique(s)
7646857	Zinc chloride	Butter of zinc	TM	s,r,p	V,IV
557211	Zinc cyanide		TM	i,r,p	III,V,IV
7783495	Zinc fluoride		TM	s,r,p	V,IV
557415	Zinc formate		TM	s,r,p	V,IV
7779864	Zinc hydrosulfite		TM	s,r,p	V,IV
7779886	Zinc nitrate		TM	s,r,p	V,IV
127822	Zinc phenosulfonate	Zinc sulfocarbolate	TM	s,r,p	V,IV
1314847	**Zinc phosphide**		TM	s,r,p	V,IV
16871719	Zinc silicofluoride	Zinc fluorsilicate	TM	s,r,p	V,IV
7733020	Zinc sulfate	White vitriol, zinc vitriol, white copperas	TM	s,r,p	V,IV
13746899	Zirconium nitrate		TM	s,r,p	V,IV
16923958	Zirconium potassium fluoride		TM	s,r,p	V,IV
14644612	Zirconium sulfate	Disulfatozirconic acid	TM	s,r,p	V,IV
10026116	Zirconium tetra-chloride		TM	s,r,p	V,IV

non-water soluble organics such as benzene. The environmentally persistent organics are those compounds which are not readily volatilized from the soil and those compounds which are not readily volatilized from the soil and are either not biodegradable or are degraded or transformed to toxic persistent residues. Examples of compounds in this category are the highly chlorinated organics such as PCBs, and nitro compounds, such as 2,4-dinitrophenol. The toxic metals category include toxic metal salts, e.g., tetraethyl lead, and metal complexes such as cupric tartrate, and heavy metals containing anions e.g., ammonium bichromate. Those anions which were considered in the toxic anions category included fluoride and cyanide salts.

The major environmental properties which determine the fate of the chemical in the environment and applicable land restoration techniques are then listed according to the following key:

- s: water soluble to the extent of greater than 50 ppm
- i: water insoluble less than 50 ppm
- b: biodegradable with complete breakdown and a half-life in soil (actual or predicted) of less than 4 months
- r: chemically or photochemically reactive
- t: biotransformed organic
- u: biouseable inorganic
- v: volatile from soil due to high vapor pressure codistillation with water, water insolubility
- p: persistent toxic residue
- n: persistent non-toxic residue

The last column in the table lists potential restoration techniques which could be applicable to spills of the chemical after the initial spill clean-up.

I - No treatment

II - Biodegradation

III - Neutralization

IV - Vegetative Uptake

V - Physical removal

VI - Chemical reactions

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 227)
TYPING GUIDE SHEET

VII - Optimization of photodegradation

VIII - Revegetation

ASSESSING THE DAMAGE TO THE LAND

Before any land restoration technique can be employed, the extent of the damage must first be assessed. Sampling of the spill area with either a soil corer or trowel. The sampling scheme should outline the spill area and cross it to determine how far the spill had spread laterally, to what soil depths, and the areas of high concentration of the chemical. A sample of undamaged soil should also be taken. The samples should be sealed in containers, cooled and returned to a laboratory for immediate analyses. The following analyses are recommended:

- chemical concentration
- soil pH
- exchangeable sodium percentage
- electrical conductivity
- soil bacteria and actinomycetes

Soil pH, exchangeable sodium, electrical conductivity, and populations need only be performed on a few of the samples, i.e., two from the areas of high concentration of the spilled chemical, two from the fringes of the spill area, and one from undamaged soil. Procedures for these analyses can be found in standard reference texts.

The results of these analyses will help determine the amount of damage done to the soil by the spill and provide useful information to help in the decision on the restoration technique to be used.

SELECTION OF THE APPROPRIATE LAND RESTORATION TECHNIQUE

A flow diagram to aid the On Scene Coordinator (OSC) in selection of appropriate land restoration techniques for a particular spill situation is presented in Figure 57. It must be remembered that this guide is very preliminary in that it is based on a limited number of actual land restoration attempts and laboratory experiments. This flow chart should be updated as more information becomes available and can be catalogued for each chemical.

APPLICATION OF THE LAND RESTORATION TECHNIQUE

Each of the potential land restoration techniques shown in Figure 57 and Table 61 have many variations which can be modified to fit a specific spill situation. The application of the techniques and potential modification thereof are discussed in the following sections.

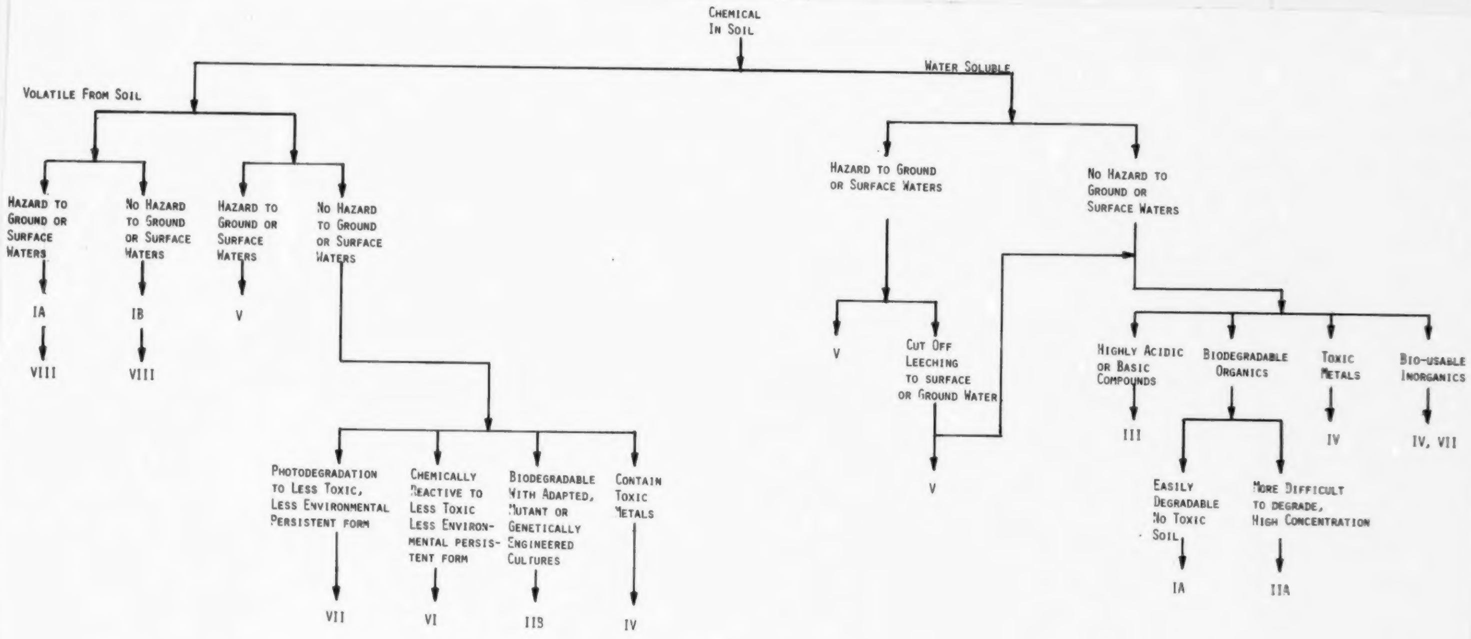

CHEMICAL IN SOIL
VOLATILE FROM SOIL
WATER SOLUBLE
HAZARD TO GROUND OR SURFACE WATERS
IA
VIII
NO HAZARD TO GROUND OR SURFACE WATERS
IB
VIII
HAZARD TO GROUND OR SURFACE WATERS
V
NO HAZARD TO GROUND OR SURFACE WATERS
PHOTODEGRADATION TO LESS TOXIC, LESS ENVIRONMENTAL PERSISTENT FORM
VII
CHEMICALLY REACTIVE TO LESS TOXIC LESS ENVIRONMENTAL PERSISTENT FORM
VI
BIODEGRADABLE WITH ADAPTED, MUTANT OR GENETICALLY ENGINEERED CULTURES
IIB
CONTAIN TOXIC METALS
IV
HAZARD TO GROUND OR SURFACE WATERS
V
CUT OFF LEECHING TO SURFACE OR GROUND WATER
V
NO HAZARD TO GROUND OR SURFACE WATERS
HIGHLY ACIDIC OR BASIC COMPOUNDS
III
BIODEGRADABLE ORGANICS
EASILY DEGRADABLE NO TOXIC SOIL
IA
MORE DIFFICULT TO DEGRADE, HIGH CONCENTRATION
IIA
TOXIC METALS
IV
BIO-USABLE INORGANICS
IV, VII

Figure 57. Logic tree for selection of appropriate restoration techniques.

IA, IB. No Specific Land Treatment

For those compounds which readily volatilize from the soil or which are non-toxic to the soil in high concentrations and easily biodegraded, no specific treatment is necessary for removal of the chemical from the land. If the ground water or surface water is endangered by the spilled material, IA, a barrier to the transport of the material into these waterways will be necessary. This barrier could take the form of a dam, grout curtain, etc. depending on the geology and hydrology of the area. If ground or surface water is not threatened, the material should be allowed to escape from the soil naturally or be taken up by plants or microorganisms. Revegetation of the area (VIII) may be necessary in some cases.

IIA, IIB, Biodegradation

Biodegradation is most applicable for water soluble, non-persistent, organics (IIA) which are present in low concentrations (less than 1000 ppm). For biodegradation of water soluble non-persistent organics, two methods can be used - in situ biodegradation or washing the chemical out of the soil into a biodegradation pond or ditch. In situ biodegradation can be accomplished by repeatedly adding to the soil a mixed culture of organisms obtained from sewage or from a biotreatment pond with nutrients, e.g., yeast extract, and minerals. This process is continued until the concentration of the chemical contaminant has been reduced to a safe level. The cost of this treatment is relatively low since the only equipment necessary is a spray hose, pump and mixing tank.

Removal of the chemical from the soil by flushing it into a biotreatment pond provides a more rapid method of land restoration. The soil is cleansed quickly and biodegradation occurs more rapidly in the aqueous media than in the soil. This method is more expensive than in situ treatment.

The use of biodegradation to remove from the soil persistent chemicals such as the chlorinated pesticides is a new technique which has potential for the future. The organisms for degrading a specific chemical must be known and immediately available. Identification of, or engineering of, specific cultures of organisms to degrade these compounds requires future research. In addition, for these organisms to be useful in a spill situation, they must be stored in an accessible location for immediate culturing.

Neutralization

Acidic or basic compounds may only require neutralization for restoration of the land or neutralization may be required to convert the chemical to a more biodegradable form. The neutralization techniques employed depends on the compound. Previously used in situ soil neutralization methods include the addition of lime for neutralization of acids and the addition of alum for neutralization of caustic chemicals. Other techniques may be employed after neutralization, e.g. biodegradation, revegetation.

Vegetative Uptake

The use of vegetation to remove metals and some organics from the soil is an inexpensive method of land restoration. The method is slow, requiring several growing seasons and harvesting and disposal of the plant tissue. It is most useful for areas where ground or surface water contamination is not a problem.

Plants selected for this restoration method must be able to accumulate the metal or organic, and grow well under the climatic conditions and soil conditions of the spill site. Grasses and grains are probably the most useful plants for vegetative uptake. Most are hardy, tolerate and grow well under a variety of climatic and soil conditions. For the method to work well, soil pH should be optimized to increase metal availability. A chelating agent should also be applied periodically to aid in the plant uptake.

V, Physical Removal

For highly persistent or toxic compounds spilled on valuable land, or in situations where the spill threatens water sources, the only alternative may be physical removal of the chemical from the soil. Several types of physical removal have been employed to treat land damaged by spills of hazardous chemicals:

1) dig up the soil, package and send to an approved hazardous landfill; refill with uncontaminated soil and revegetate

2) dig up and process the soil to remove the chemical; degrade the chemical in the extract; return the soil and revegetate

3) extract the soil in situ by flushing with water, treat the extract, e.g. carbon adsorption and, revegetate the soil

4) solidify the soil to prevent movement of toxic chemicals

Methods 1-3 all remove the material from the soil, however, they are very expensive. Method 4 simply stops the movement of the hazardous material until a proper treatment methodology can be found.

VI, Chemical Reactions

In situ chemical reactions (other than neutralization) can degrade some persistent chemicals to the point where natural degradation processes can take over. This type of treatment must be evaluated on an individual spill basis. The damage the reactant will do to the soil must be carefully assessed, so as not to cause more damage than the original spill.

VII, Optimization of Photodegradation

Photochemical degradation of persistent organics, e.g., polychlorinated organics, has long been overlooked as a viable method of degrading these chemicals in the environment. This technique works best on soils that are nonporous and retain the spilled material in the top layer. For this technique to be useful, photodegradation conditions must be optimized as soon after the spill as possible. Usually the only optimization process needed is to provide a hydrogen donor source. This source can be in the form of a biodegradable oil, e.g., olive oil. Another optimization procedure which can be used in addition to the adding of the hydrogen donor source is adjustment of pH, usually to the basic range. The photodegradation of many poly-halogenated compounds under these optimization conditions will proceed rapidly if sunlight is available and rain does not wash the chemical into the soil.

VIII, Revegetation

After the spill clean-up, during and after land restoration steps must be taken to prevent the damaged soil from eroding. If the land is toxic to plants, a mulch material such as straw, burlap can be applied to the area to lessen erosion. As soon as the land will support vegetation, revegetation of the area is suggested. Plants which could be used for revegetation are listed in Table 62.

TABLE 62. VEGETATION RECOMMENDATIONS TO COVER LAND CONTAMINATION WITH HAZARDOUS MATERIALS

Soil	Plant	Adaptation
Acid	Crown Vetch, *Cornilla Varia*	drought tolerant, cool season
	Lespedezas, *Lespedeza sp.*	warm season
	Rye, *Secale cereale*	cool season
	Reedcanary grass, *Phalaris arundinacea*	cool season, drought tolerant adapted to very wet conditions drought tolerant, warm season
Alkaline, Salt Contaminated Soils	Barley, *Hordium vulgare*	cool season
	Tall Wheatgrass, *Agropyron eldingatom*	warm season, poorly drained soils
	Western Wheatgrass, *Agropyron smithii*	warm season, dry soils
	Bermuda grass, *Cynodon dactylon*	warm season, drought tolerant
	Birdsfoot trefoil, *Lotus corniculatus*	cool season, drought tolerant
	Cotton, *Gossypium hirsutom*	warm season, draught tolerant
	Reedeanary grass, *Phalaris arundinacea*	cool season, drought tolerant adapted to very wet conditions
	Tall Fescue, *Festuca arundinaces*	cool season
Metal Contaminated	Browntop, *Agrostis Tenis*	cool season
	Red Fescue, *Festura Rubra*	cool season, shade grass
	Barley, *Hordeum Vulgare*	cool season
	Giant Bermuda grass, *Cynddon Dactylon*	warm season, drought tolerant
	Rye, *Secale Cereale*	cool season

REFERENCES

Anthony, C. 1975. The Biochemistry of Methylotrophic Micro-Organisms. Sci. Prog. 62:207.

Armiger, W.H., J.N. Jones, and O.L. Bennett. 1976. Revegetation of Land by Strip Mining of Coal in Appalachia. Agricultural Research Service. Report ARS-NE-71. 38 pp.

Bartlett, A. 1978. Acrylonitrile Spill, Leon, Ky., January 30, 1978. File Copy, March 1, 1978, EPA, Atlanta, GA.

Bennett, O.L., W.H. Armiger, and J.N. Jones, Jr. 1976. Revegetation and Use of Eastern Surface Mine Spoils. In: Land Application of Waste Materials. Soil Conservation Society of American, Ankeny, IA. pp. 195-215.

Berry, W.L. 1977. Dose-Response Curves for Lettuce Subjected to Acute Toxic Levels of Copper and Zinc. In: Biological Implications of Metals in the Environment, ERDA Symposium Series 42, CONF-750929, pp. 365-369. Drucker, H. and R.E. Wildung, Chairmen.

Black, C.A., editor. 1965. Methods of Soil Analysis. Part 2: Chemical and Microbial Properties. Agronomy Monograph 9, American Society of Agronomy, Inc., Madison, WI. 1572 pp.

Blanchard, F.A., W.W. Muelder, and G.N. Smith. 1960. Synthesis of Carbon-14-Labeled Dalapon and Trial Applications to Soybean and Corn Plants, J. Agr. Food Chem. 8:124.

Burger, K., L.C. MacRae, M. Alexander. 1962. Soil Sci. Amer. Proc. 26:1343. In: Alexander, M. 1973. Nonbiodegradable and Other Recalcitrant Molecules (Biotechnology Report). Biotech. and Bioeng. XV(4):621.

Burnside, O.C., G.A. Wicks, C.R. Fenster. 1971. Weed Sci. 19:323. In: M. Alexander. 1975. Nonbiodegradable and Other Recalcitrant Molecules (Biotechnology Report). Biotech. and Bioeng. XV(4):621.

Byast, T.H., and R.J. Hance. 1975. Degradation of 2,4,6-T by South Vietnamese Soils Incubated in the Laboratory. Bull Env. Contam. and Tox. 14:71-75.

Chen, J.S., N.S. Talekar, L.T. Sun, E.M. Lee. 1977. Persistence of Some Insecticides in Subtropical Soil. J. Agric. Food Chem. 25(2):348-352.

CHRIS. 1974. Hazardous Chemical Data. U.S. Department of Transportation, Coast Guard. CG-446-2.

Corbin, F.T. 1965. The Influences of pH on the Detoxification of Herbicides in Soil. Ph.D. Thesis, N.C. State University, Raleigh, N.C.

Crosby, D.G. 1977. Photochemical Destruction of Chlorodioxins. Presented at the 1977 Annual ACS Meeting, Chicago, Illinois, August 28-September 2.

Darnell, A.J. 1978. Disposal of Spilled Hazardous Materials by the Bromination Process. Control of Hazardous Material Spills. Proceedings of 1978 National Conference on Control of Hazardous Material Spills. pp. 221-225.

Day, B.E., L.S. Jordan, R.C. Russel. 1963. Persistence of Dalapon Residues in California Soils. Soil Sci. 95:326.

DeRose, H.R., and A.S. Newman. 1947. Soil Sci. Soc. Amer. Proc. 12:222. In: M. Alexander. 1973. Nonbiodegradable and Other Recalcitrant Molecules (Biotechnology Report). Biotech. and Bioeng. XV(4):621.

Federal Register. 1978. Water Programs. Hazardous Substances. 43(49):10474-10508.

Fox, C.J. 1964. The Effects of Five Herbicides on the Numbers of Certain Invertebrate Animals in Grassland Soil. Can. J. Plant Sci. 44:405.

Foy, C.L. 1961. Absorption, Distribution and Metabolism of 2,2-dichloropropionic Acid in Relation to Phytotoxicity. II. Distribution and Metabolic Fate of Dalapon in Plants. Pl. Physiol. 36:698.

Fung, K.H. 1976. Foliar Damage, Residue Levels and Tuber Yield in Potato Treated with Various Concentrations of 2,4-D at Three Stages of Growth. Aust. J. Exp. Agric. Anim. Hubs. 16(80):423-427.

Giordano, P.M. and D.A. Mays. 1977. Yield and Heavy-Metal Content of Several Vegetable Species Grown in Soil Amended with Sewage Sludge. In: Biological Implications of Metals in the Environment. ERDA Symposium 42, CONF-750929. pp. 417-425. H. Drucker and R.E. Wildung, Chairmen.

Haque, R. and V.H. Freed, editors. 1975. Environmental Dynamics of Pesticides, Plenum Press, NY. pp. 136-163.

Harsh, K. 1978. In Situ Neutralization of an Acrylonitrile Spill. Proceedings of the 1978 National Conference on Control of Hazardous Material Spills. pp. 187-189.

Hautala, R.R. 1978. Surfactant Effects on Pesticide Photochemistry in Water and Soil. EPA-600/3-78-060, U.S. Environmental Protection Agency, Atlanta, GA.

Hetrick, L.A. 1952. J. Econ. Entomol. 45:235. In: M. Alexander. 1973. Nonbiodegradable and Other Recalcitrant Molecules (Biotechnology Report). Biotech. and Bioeng. XV(4):621.

Huibregtse, K., J.P. Lafornara, and K.H. Kastman. 1978. In Place Detoxification of Hazardous Materials Spills in Soil. Control of Hazardous Material Spills, Proceedings of the 1978 National Conference on Control of Hazardous Material Spills. pp. 362-370.

Issac, R.A. and J.D. Kerber. 1971. Atomic Absorption and Flame Photometry: Techniques and Uses in Soil, Plant and Water Analysis. In: Instrumental Methods for Analysis of Soils and Plant Tissue. L.M. Walsh, editor, Soil Science Society of America, Inc., Madison, WI. pp. 17-32.

Iwata, Y., M. Dusch, W.E. Westlake, and F.A. Gunther. 1975. Behavior of Five Organophosphorus Pesticides in Dust Derived from Several Soil Types, Bul. Environ. Contam. and Toxic. 14(1):49-56.

Kearney, P.C., D.D. Kaufman, and M.L. Beall. 1964. Enzymatic Dehalogenation of 2,2-dichloropropionate. Biochem. Biophys. Res. Comm. 14(1):29.

Kuwatsuak, S. and Y. Niki. 1976. Fate and Behavior of Herbicides in Soil Environment with Special Emphasis on the Fate of Principal Paddy Herbicides in Flooded Soils. Review of Plant Protection Research. 9:143-163.

Larsen, F.E. 1974. Rootstock Influence on 2,4-D Damage to Barlett and d'Anjou Pear Trees. Hort. 9(6, Sect. 1):593-594.

Latimer, W. 1932. Soil Survey of Rensselear County, New York. Soil Conversation Service, Washington, D.C.

Leonard, R.A., G.W. Bailey, and R.R. Swank, Jr. 1976. Transport, Detoxification, Fate and Effects of Pesticides in Soil and Water. Presented at Soil Conservation Society of American Conference on Land Application of Waste Materials, Des Moines, March 15-18. pp. 48-78.

Lichtenstein, E.P., T.W. Fuhremann, and K.R. Schulz. 1971. J. Agr. Food Chem. 19:718. In M. Alexander. 1973. Nonbiodegradable and Other Recalcitrant Molecules (Biotechnology Report). Biotech. and Bioeng. XV(4)-:621.

Lichtenwalner, H. 1977. Duty Officer Report - Train Derailment. File ref. 3210 August 5th, Department of Natural Resources, Madison, WI.

Matsumura, F. and G.M. Boush. 1968. Degradation of Insecticide by a Soil Fungus, *Trichoderma viride*. J. Econ. Ent. 61:610-612.

Mercer, B., G. Dawson, L. Ames, J. McNeese, and E. Baker. 1978. Current Methodology for Disposal of Spilled Hazardous Material Spills. Proceedings of the 1978 National Conference on Control of Hazardous Material Spills. pp. 190-195.

Moein, G. 1976. Study of the Distribution and Fate of Polychlorinated Biphenyls and Benzenes After Spill of Transformer Fluid. EPA 904/9-76-014. U.S. Environmental Protection Agency, Atlanta, Georgia.

Moein, G., A. Smith, and P. Stewart. 1976. Follow-up Study of the Distribution and Fate of Polychlorinated Biphenyls and Benzenes in Soil and Ground Water Samples after an Accidental Spill of Transformer Fluid. Proceedings of the 1976 National Conference on Control of Hazardous Material Spills. pp. 368-372.

Mortvedt, J.J. and P.M. Giordano. 1977. Crop Uptake of Heavy-Metal Contamination. In: Biological Implications of Metals in the Environment. ERDA Symposium Series. 42, CONF-750929, pp. 402-416. H. Drucker and R.E. Wildung, Chairmen.

Nash, R.G. and E.A. Woolson. 1967. Science 157:924. In: M. Alexander. 1973. Nonbiodegradable and Other Recalcitrant Molecules (Biotechnology Report). Biotech. and Bioeng. XV(4):621.

Natural Resources Department. 1972-1973. Chemical Data Files, Cumberland Office, MD.

Paschal. D.C. and M.E. Neville. 1976. Chemical and Microbial Degradation of Malaoxon in an Illinois Soil. J. Environ. Qual. 5(4):441-443.

Ramsey, L. and J.M. MacCrum. 1974. How to Cope with Hazardous Spills: A Case History. Proceedings of the 1974 National Conference on Control of Hazardous Material Spills. pp. 234-237.

Roush, T., J. Lafornara, and R. Nadeau. 1974. A Case History of a Formalin Spill: A Preliminary Approach for Impact Assessment. Proceedings of the 1974 National Conference on Control of Hazardous Material Spills. pp. 359-362.

Ruffner, J. and F. Blair. 1978. Climates of the States. Gale Research Company, Detroit, MI.

Sahai, R. and M. Chauhan. 1977. Pesticidal Pollution. J. Sci. and Ind. Res. 36(12):685-693.

Smith, G.N. and D.L. Dyer. 1961. Fate of 2,2-dichloropropionic Acid (Dalapon) in the Cotton Plant, J. Agri. Food Chem. 9:155.

SRI. 1979. Directory of Chemical Producers. United States of America. SRI International, Menlo Park, CA.

SRI. 1980. Directory of Chemical Producers. United States of America. SRI International, Menlo Park, CA.

Stanier, R., M. Doudoroff, and E. Adelburg. 1963. The Microbial World, 2nd edition. Prentice-Hall Inc., Englewood Cliffs, NJ. p. 30.

Stewart, D.K. and D. Chisholm. 1971. Can. J. Soil. Sci. 51:379. In: M. Alexander. 1973. Nonbiodegradable and Other Recalcitrant Molecules (Biotechnology Report). Biotech. and Bioeng. XV(4):621.

Stewart, D.K., D. Chisholm, and M.T. Rogab. 1971. Nature. 229:47. In: M. Alexander. 1973. Nonbiodegradable and Other Recalcitrant Molecules (Biotechnology Report). Biotech. and Bioeng. XV(4):621.

Stewart Laboratories, Inc. 1978. In: Acrylonitrile Spill, Leon, Kentucky, January 30, 1978. A. Bartlett, File copy, March 1, 1978. U.S. Environmental Protection Agency, Atlanta, GA.

Stojanovic, B.J., M.V. Kennedy, and F.L. Shuman. 1972. Edaphic Aspects of the Disposal of Unused Pesticides, Pesticide Wastes, and Pesticide Containers. J. Env. Quality. 1:54-62.

Thompson, J.F. 1974. Analysis of Pesticide Residues in Human and Environmental Samples. U.S. Environmental Protection Agency, Research Triangle Park, N.C. Revised December 1974.

Tiedje, J.M. 1977. Influence of Environmental Parameters on EDTA Biodegradation in Soils and Sediments. J. Env. Qual. 6(1):21-26.

Tiffin, L.O. 1977. The Form and Distribution of Metals in Plants: An Overview. In: Biological Implications of Metals in the Environment. ERDA Symposium Series 42. CONF-750929. H. Drucker and R.E. Wildung, Chairmen. pp. 365-369.

USDA. 1977. Soil Survey - Allegany County, Maryland. Soil Conservation Service, Washington, D.C.

USDA. 1976. Soil Survey - Montgomery County, Ohio. Soil Conservation Service, Washington, D.C.

USDA. 1971. Soil Survey - Walworth County, Wisconsin. Soil Conservation Service, Washington, D.C.

USDA. 1960. Soil Survey - Newton County, Mississippi. Soil Conservation Service, Washington, D.C.

U.S. Geological Survey. 1978. Map Series V853, Kentucky.

U.S. Geological Survey. 1974. Map Series V852, Ohio.

U.S. Geological Survey. 1974. Map Series V833, Maryland.

U.S. Geological Survey. 1971. Map Series V861. Wisconsin.

U.S. Geological Survey. 1966. Map Series V897, Utah.

U.S. Geological Survey. 1957. Map Series, Chunky, Mississippi.

U.S. Geological Survey. 1953. Map Series V821, New York.

U.S. Geological Survey. 1945. Map Series Varnville, South Carolina.

Udo, E.J. and A.A.A. Fayemi. 1975. Effect of Oil Pollution of Soil on Germination, Growth, and Nutrient Uptake of Corn. J. Env. Qual. 4(4):537-540.

Verschueren, K. 1977. Handbook of Environmental Data on Organic Chemicals. Van Nostrand Reinhold Co., New York, NY. p. 659.

Walker, W.W. and B.J. Stojanovic. 1973. Microbial Versus Chemical Degradation of Malathion in Soil. J. Env. Qual. 2(2):229-232.

Wallace, A., E. Romney, and P. Patel. 1978. Role of Synthetic Chelating Agents in Trace Metal Uptake by Plants. Env. Chem. Cycling Processes. 1976. DOE Symp. Ser. #45. CONF-760429. pp. 645-657.

Wallace, A. and E.M. Romney. 1977. Roots of Higher Plants as a Barrier to Translocation of Some Metals to Shoots of Plants. In: Biological Implications of Metals in the Environment. ERDA Symposium Series 42, Conf-750929. H. Drucker and R.E. Wildung, Chairmen. pp. 370-379.

Weldon, L.W. and F.L. Timmons. 1961. Weeds. 9:195. In: M. Alexander. 1973. Nonbiodegradable and Other Recalcitrant Molecules (Biotechnology Report). Biotech. and Bioeng. XV(4):621.

Whitney, M. 1915. U.S. Department of Agriculture, Department of Soils, Washington, D.C.

Woodward, L. 1925. Soil Survey on Aeber Valley Area, Utah. Soil Conservation Service, Washington, D.C.

Zutshi, U. and B.L. Kaul. 1975. Cytogenetic Activity of Some Common Fungicides in Higher Plants. Cytobios. 12(45):61-67.

APPENDIX A

BACKGROUND DATA ON HAZARDOUS CHEMICALS USED IN LABORATORY TESTS

MONOCHLOROBENZENE

Monochlorobenzene is a high production chemical which is used as a solvent and as an intermediate in phenol, aniline, chloronitrobenzene and pesticide manufacture. This chemical is currently produced by six U.S. companies (SRI, 1979).

Product	Location	Annual Capacity Millions of kg	(lbs)
Allied Chemical Corp Indust. Chem. Division	Syracuse, NY	9.1	(20)
Dow Chemical U.S.A.	Midland, MI	99.8	(220)
Monsanto Co. Monsanto Intermed. Co.	Sauget, IL	68.0	(150)
Montrose Chem. Corp. of California	Henderson, NE	31.8	(70)
PPG Indust., Inc. Chem. Group Chem. Division - U.S.	Natrium, WV	40.8	(90)
Standard Chlorine Chem. Company, Inc.	Delaware City, DE	68.0	(150)

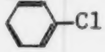
Total U.S. production capacity is 318 million kilograms (700 million pounds) per year.

The pertinent physical, chemical and biological properties of monochlorobenzene are listed in Table A-1. Based on these properties and its large production volume, monochlorobenzene was chosen as a representative compound for evaluation of techniques to restore spill damaged land.

ETHION

ETHION (O,O,O',O'-tetraethyl-S, S'-methylene biphosphorodithioate) is an

TABLE A-1. PHYSICAL CHEMICAL AND BIOLOGICAL PROPERTIES OF MONOCHLOROBENZENE (VERSCHUEREN, 1977)

Molecular Formula:	C_6H_5Cl		
Structural Formula:			
Molecular Weight:	112.56		
Physical Form @ 20°C:	colorless liquid		
Odor:	honey suckle		
Melting Point:	-45°C		
Boiling Point:	132°C		
Vapor Pressure:	1170 Pa (8.8 torr) @ 20°C 1570 Pa (11.8 torr) @ 25°C 1940 Pa (15 torr) @ 30°C		
Vapor Density:	3.88		
Specific Gravity:	1.1066		
Water Solubility:	500 mg/1 @ 20°C 488 mg/1 @ 30°C		
Biological Degradation:	100% ring disruption of 200 mg/1 by *Pseudomonas* in 58 hours		
BOD_5	0.03 standard dilution sewage		
Biological Effects:	*bacteria*:	inhibition of cell *multiplication of Pseudomonas putida*@ 17 mg/1	
	algae:	inhibition of cell multiplication of *Microcystes aeruginosa* @ 120 mg/1	
	fish:	fathead minnow TLm 29-39 mg/1 (24-96 hours)	
	mammals:	cat:	inhalation LC 50 - 8000 ppm, 30 minutes
		rat:	inhalation LC50 - 12,000 ppm, 30 minutes
		rat:	oral LD50 - 2190 mg/kg
		rabbit:	oral LD50 - 2830 mg/kg
		man:	severe toxic effects at 400 ppm (1872 mg/cm, 60 minutes) unsatisfactory - >75 ppm (35.1 mg/cm, 60 minutes)

insecticide and miticide manufactured by FMC Corporation, Agricultural Chemical Division, Baltimore, Maryland. ETHION is used for mites on cotton, forage, ornamentals, citrus, deciduous fruits, turf grasses and vegetables. As a general insecticide, ETHION can be used on 37 different food crops, cotton, sorghum and other plants.

The chemical and physical properties of ETHION presented in Table A-2. Toxicity data on ETHION are presented in Table A-3.

FORMALDEHYDE

Formaldehyde is used in the United States in the production of resins, as a starting material for chemical production, as a fumigant, and as a tissue preservative. Formaldehyde is currently manufactured by 16 U.S. companies at 54 sites (SRI, 1979). The producer, location and capacity of the plants for formaldehyde production are presented in Table A-4.

Formaldehyde is transported in large amounts on railroads, highways and waterways. It is usually shipped at a 37-40% concentration in water stabilized by the addition of 12-16% methanol. Because of formaldehyde's large use, the probability of it being spilled is high. Formaldehyde is on the Coast Guard's *CHRIS List of Hazardous Chemical Data* and is designated as a hazardous material by the EPA (Federal Register, 1978). Data on the physical, chemical and biological properties of formaldehyde are listed in Table A-5. These data indicate that a formaldehyde spill would kill the lower animals and plants and extensively harm higher animals.

ANILINE

Aniline is used in the manufacture of dyes, medicinals, resins, varnishes and perfumes. The estimated annual production of aniline is presented in Table A-6. A total of approximately 499 million kilograms (1100 million pounds) of aniline are produced per year at seven plants across the United States. The physical and chemical properties of aniline are presented in Table A-7.

CHLORDANE

Chlordane (Octachloro-4.7-methanotetrahydroindane) (Octachlorohexahydromethanoindene) (1,2,4,5,6,7,8,8-Octachloro-3*a*,4,7,7*a*-tetrahydro-4,7-methanoindan) is a pesticide and is manufactured by the Velsicol Chemical Corporation in Marshall, Illinois.

The physical and chemical properties of chlordane are presented in Table A-8.

DINITROPHENOL

Dinitrophenol is used in the production of dyes and in preserving timber. This chemical is currently produced by 2 U. S. companies (SRI, 1980).

TABLE A-2 CHEMICAL AND PHYSICAL PROPERTIES OF ETHION (FMC, 1979)

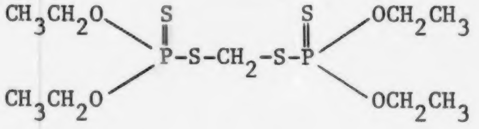
American Standards Common Name:	ETHION
Chemical Name:	0,0,0',0'-tetraethyl S,S'-methylene bisphosphorodithioate
Chemical Structure:	
Empirical Formula:	$C_9H_{22}0_4P_2S_4$
Molecular Weight:	384
Appearance:	Water white to amber colored liquid
Odor:	Typical phosphate insecticide odor
Density:	1.215 to 1.230 at 20°C
Freezing Point:	-12°C to -15°C
Solubility at 20°C:	Water 2 ppm Organic Solvents Acetone Miscible Chloroform Miscible Kerosene Miscible Methylated Naphthalene Miscible Xylene Miscible
Vapor Pressure:	2.0×10^{-4} Pa (1.5×10^{-6} torr) at 25°C
Stability:	Subject to slow oxidation in air, hydrolysis to acids and bases
Flammability:	Not flammable
Explosive Hazard:	Like other phosphate and thiophosphate esters, ETHION may decompose explosively at temperatures above 150°C
Analytical Method:	Formulations: IR Method Residues: Detection by flame photometric gas chromatograph

TABLE A-3. TOXICOLOGY OF ETHION (FMC, 1979)

Biological Effects: - Mammalia:

rat: oral LD50 (mg/kg)

Technical	70-119
25% Wettable Powder	600
Emulsifiable Concentrate (4 lbs Ethion/gal)	400
Ethion (2%) Dormant Oil Spray	6800

rat: inalation LD50 (mg/l air)

25% wettable powder	72,000

rat: intraperitoneal LD50 (mg/kg)

Ethion 4 EC	147

rabbit: dermal LD50 (mg/kg)

Technical	915
25% Wettable Powder	2172
Emulsifiable (4 lbs Ethion/gal)	2300
Ethion (2% Dormant Spray)	6800

rabbit: eye irritation
Ethion - nonirritant

- Fish: Bluegill static
96 hr LD50 95 ppb

- Wildlife - Oral LD50 (mg/kg)

	male	female
Bobwhite quail	74	73
Japanese quail	234	302
Mallard duck	1600	1600

- Man: Ethion is a cholinesterase inhibitor. Early symptoms are headache, weakness, excess perspiration, nausea, blurring vision, and tightness in chest. Later symptoms include vomiting, abdominal cramps, muscular twitching, diarrhea, and coma.

Chronic intoxication may or may not produce symptoms. Chronic intoxication is serious in that a minor additional exposure may lead to an acute serious episode of intoxication due to asymptomatic cumulative depression of choline-esterase activity.

TABLE A-4. PRODUCTION AND CAPACITY OF FORMALDEHYDE IN THE UNITED STATES (SRI, 1979)

Producer	Location	Annual Capacity Millions of kg (lbs)	
Allied Chem. Corp.			
Specialty Chems. Div.	South Point, OH	140.6	(310)
Borden Inc.			
Borden Chem. Div.			
Adhesives and Chems. Div. - East	Demopolis, AL	45.4	(100)
	Diboll, TX	36.3	(80)
	Fayetteville, NC	106.6	(235)
	Louisville, KY	36.3	(80)
	Sheboygan, WI	59.0	(130
Adhesives and Chems. Div. - West	Fremont, CA	102.0	(225)
	Kent, WA	36.3	(80)
	La Grande, OR	29.5	(65)
	Missoula, MT	40.8	(90)
	Springfield, OR	108.9	(240)
Petrochems	Geismar, LA	113.4	(250)
Celanese Corp.			
Celanese Chem. Co., Inc.	Bishop, TX	680.4	(1500)
	Newark, NJ	53.1	(117)
	Rock Hill, SC	53.1	(117)
E I du Pont de Nemours & Co.,Inc.			
Chems., Dyes and Pigments Dept.	Belle, WV	226.8	(500)
	Healing Springs, NC	99.8	(220)
	La Porte, TX	145.1	(320)
	Linden, NJ	71.6	(160)
	Toldeo, OH	122.5	(270)
GAF Corp.			
Chem. Products	Calvert City, KY	45.4	(100)
Georgia-Pacific Corp.			
Chem. Div.	Albany, OR	59.4	(120)
	Columbus, OH	90.8	(200)
	Coos Bay, OR	40.8	(90)
	Crossett, AR	72.6	(160)
	Lufkin, TX	47.4	(100)
	Russelville, SD	90.8	(200)
	Taylorsville, MS	54.4	(120)
	Vienna, GA	45.4	(100)

(continued)

TABLE A-4. (continued)

Producer	Location	Annual Capacity Millions of kg	(lbs)
Getty Oil Co.			
Chembond Corp., subsid	Andalusia, AL	31.8	(70)
	Springfield, OR	63.6	(140)
	Winnifield, LA	31.8	(70)
Gulf Oil Corp.			
Gulf Oil Chem. Co.			
Indust. & Specialty Chem. Div.	Vicksburg, MS	20.4	(45)
Hercules Inc.	Louisiana, MO.	77.1	(170)
	Wilmington, NC	45.4	(100)
International Minerals & Chem. Corp.			
IMC Chem. Group	Seiple, PA	79.5	(65)
	Sterlington, LA	13.6	(30)
Monsanto Co.			
Monsanto Plastics & Resins Co.	Addyston, Ohio	45.4	(100)
	Chocolate Bayou, TX	88.5	(195)
	Eugene, OR	45.4	(100)
	Springfield, MA	133.8	(295)
Occidental Petroleum Corp.			
Hooker Chem. Corp., Subsid.			
Hooker Chem. and Plastics Corp., subsid.			
Durez Div.	North Tonawanda, NY	61.2	(135)
Reichhold Chem., Inc.	Hampton, SC	22.7	(50)
	Houston, TX	54.4	(120)
	Kansas City, KS	22.7	(50)
	Malvern, AR	49.9	(110)
	Moncure, NC	54.4	(120)
	Tacoma, WA	21.8	(48)
	Tuscaloosa, AL	32.7	(72)
	White City, OR	113.4	(250)
Tenneco Inc.			
Tenneco Chem., Inc.	Fords, NJ	83.9	(185)
	Garfield, NJ	45.4	(100)
Univar Corp.			
Pacific Resins & Chem., Inc., subsid.	Eugene, OR	43.1	(95)

(continued)

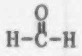
TABLE A-4 (continued)

Producer	Location	Annual Capacity Millions of kg	(lbs)
Wright Chem. Corp	Acme, NC	76.3	(80)
	TOTAL	4116.1	(9074)

Note: Capacity figures are on a 37% basis

Source: SRI International estimates

TABLE A-5. PHYSICAL, CHEMICAL AND BIOLOGICAL PROPERTIES OF FORMALDEHYDE (VERSCHUEREN, 1977)

Molecular Formula:	HCHO
Structural Formula:	 $\mathrm{H{-}\overset{\overset{\displaystyle O}{\Vert}}{C}{-}H}$
Molecular Weight:	30.0
Physical Form @ 20°C:	gas
Odor:	hay; strawlike; pungent
Melting Point:	-92°C
Boiling Point:	-19°C
Vapor Pressure:	1330 Pa (10 torr) at -88°C
Vapor Density:	1.03
Specific Gravity:	0.815 at 4°C
Commercial Formaldehyde Solution:	
HCHO, wt%	37
Boiling Point	98.9
Density at 18°C	1.11 g/ml
Flash Point	85.0°C
Air Pollution TLV :	3 ppm (USA)
BOD_5 :	0.33 - 1.06 std. dil. sewage
Biological Degradation:	$HCHO \xrightarrow{+\ 1/2\ O_2} CHOOH \xrightarrow{+1/2\ O_2} CO_2 + H_2O$ $HCHO \xrightarrow{+\ H_2} CH_3OH \xrightarrow{+1\ 1/2\ O_2} CO_2 + 2H_2O$
Biological Effects:	- Bacteria: E. coli: Toxic: 1 mg/l Pseudomonas putida: inhibition of cell

(continued)

TABLE A-5 (continued)

- multiplication starts at 0.39 mg/l for a 35% solution
- Algae: Scenedesmus: Toxic: 0.3-0.5 mg/l
- Microcystis Aeruginosa: inhibition of cell multiplication starts at 0.39 mg/l for a 35% solution
- Arthropoda: Daphnia: toxic: 2 mg/l
- Fish:

  sensitive aquatic organisms: TLm 50-2000 mg/l
- Mammalia:

  guinea pig: single oral LD50: 0.26 g/kg

  rat: single oral LD50: 0.1-0.8 g/kg

  rat: inhalation: LC50: 250 ppm, 4 hr.
  830 ppm, 30 min.

  cat: inhalation: LC50: 650 ppm, 8 hr.
  all survived:
  200 ppm, 3.5 hr.
- Man:

  severe toxic effects: 100 ppm=120 mg/cu m, 1 min.

  symptoms of illness: 30 ppm= 36 mg/cu m

  unsatisfactory: 10 ppm= 12 mg/cu m

TABLE A-6. ESTIMATED ANNUAL PRODUCTION OF ANILINE IN THE UNITED STATES (SRI, 1980)

Producer	Location	Annual Capacity Millions of Kilograms	(pounds)	Raw Material
American Cyanamid Co.	Bound Brook, N.J.	37.2	(60)	Nitrobenzene
Organic Chemi. Div.	Willow Island, W. Va.	22.7	(50)	Nitrobenzene
E.I. du Pont de Nemours & Co., Inc.	Beaumont, Tex.	104.3	(230)	
Chemi. Dyes and Pigments Dept.	Gibbstown, N. J.	77.1	(170)	Nitrobenzene
First Mississippi Corp. First Chem. Corp. Subsid.	Pascagoula, Miss.	113.4	(250)	Nitrobenzene
Mobay Chem. Corp. Indust. Chem. Div.	New Martinsville, W. Va.	45.4	(100)	Nitrobenzene
Rubicon Chem. Inc.	Geismar, La.	127	(280)	ICI Process
	TOTAL	517.1	(1,140)	

TABLE A-7. PHYSICAL AND CHEMICAL PROPERTIES OF ANILINE

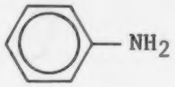
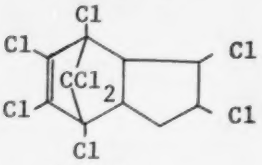
Molecular Formula:	$C_6H_5NH_2$	
Structural Formula:		
Molecular Weight:	93.1	
Physical Form @ 20°C:	liquid	
Melting Point:	-6°C	
Boiling Point:	184° C	
Vapor Pressure:	133 Pa (1 torr) at 35°C, 40 Pa (.3 torr) at 20°C	
Vapor Density:	3.22	
Specific Gravity:	1.02	
Solubility:	Water	34,000 mg/l
	Alcohol	miscible
	Benzene	miscible
	Chloroform	miscible

TABLE A-8. PHYSICAL AND CHEMICAL PROPERTIES OF CHLORDANE

Molecular Formula:	$C_{10}H_6Cl_8$
Structural Formula	
Molecular Weight	409.8
Physical Form @ 20°C	Amber-colored liquid
Density	1.59-1.63 at 25°C
Solubility	Insol. in water Miscible in aliphatic and aromatic hydrocarbons

Producer	Location
Martin Marietta Corp Martin Marietta Chem. Sodyeco Division	Sodyeco, NC
Mobay Chem. Corp	
Dyestuff Division	Bushy Park, SC
Indust. Chem. Division	Bushy Park, SC

The physical, chemical and biological properties of dinitrophenol are presented in Table A-9.

LEAD NITRATE

Lead which is used as a mordant in dyeing and printing calico, matches, paint pigment, mordant for staining mother of pearl, oxidizer in the dye industry, sensitizer in photography, explosives, tanning, process engraving, and lithography. Lead nitrate is manufactured by the following companies.

Producer	Location
Richardson-Merrell, Inc. J.T. Baker Chem. Co. sub.	Phillipsburgh, NJ
G. Frederick Smith Chem. Co.	Columbus, OH

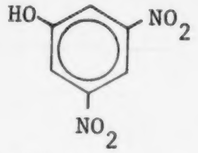
The physical and chemical properties of lead nitrate are presented in Table A-10.

CADMIUM NITRATE

Cadmium nitrate is used as a starting material for nickel-cadmium and silver-cadmium alkaline storage batteries. Generally cadmium is used in the electroplating industry and batteries. Cadmium nitrate is manufactured by the following companies.

Producer	Location
Allied Chem. Corp Chem. Co.	Buffalo, NY Marcus Hook, PA
W.A. Cleary Corp.	Somerset, NJ
Gulf Oil Corp. Harshaw Chem. Co. sub. Indust. Chem. Dept.	Cleveland, OH
The Hall Chem. Co.	Arab, AL
McGean Chem. Co., Inc.	Cleveland, OH

TABLE A-9. PHYSICAL, CHEMICAL AND BIOLOGICAL PROPERTIES OF DINITROPHENOL (VERSCHUEREN, 1977)

Molecular Formula:	$(NO_2)_2\ C_6H_3OH$
Structural Formula	
Molecular Weight	184.11
Physical Form @ 20°C	Yellow rhombic crystals
Melting Point	111-114°C
Vapor Density	6.36
Specific Gravity	1.683 at 24°C
Water Solubility	5600 mg/l at 18°C 43000 mg/l at 100°C

AIR POLLUTION FACTORS: 1 mg/cu m = 0.13 ppm, 1 ppm = 7.65 mg/cu m
--T.L.V.: USSR: 0.007 ppm = 0.05 mg/cu m 1971 (n.s.i.)

WATER POLLUTION FACTORS:
--Water quality:
M.A.C. in waters class I for the production of drinking water: 0.03 mg/l

--Biodegradation:
adapted culture: 2% removal after 48 hr incubation, feed: 200 mg/l
adapted A.S. at 20°C--product is sole carbon source: 85.0% COD removal at 6.0 mg COD/g dry inoculum/hr
--Impact on biodegradation processes:
inhibition of degradation of glucose by Pseudomonas fluorescens at: 3 mg/l
inhibition of degradation of glucose by E. coli at: >100 mg/l

BIOLOGICAL EFFECTS:
--Bacteria:
E. coli: toxic: 100 mg/l
Pseudomonas putida: inhibition of cell multiplication starts at 115 mg/l

--Algae:
Scenedesmus: toxic: 40 mg/l
Microcystis aeruginosa: inhibition of cell multiplication starts at 33 mg/l
--Arthropoda: Daphnia: toxic: 6 mg/l
--Man: unsatisfactory: >1 mg/cu m (n.s.i.)

TABLE A-10. PHYSICAL, CHEMICAL AND BIOLOGICAL PROPERTIES OF LEAD NITRATE (HAWLEY, 1977)

Molecular Formula	$Pb(NO_3)_2$
Molecular Weight	331.2
Physical form @ 20°C	White crystals
Melting Point	--
Boiling Point	Decomposes at 470°C
Specific Gravity	4.53
Solubility	Water 37.65 g/100 cc at 20°C
Biological Effects:	Rat, oral LDLo: 432 mg/kg intravenous LDLo: 50 mg/kg

Richardson-Merrell, Inc. J.T. Baker Chem. Co. sub.	Phillipsburg, NJ
The Shepherd Chem. Co.	Cincinnati, OH
United Catalysts Inc.	Louisville, KY

The physical and chemical properties of cadmium nitrate are presented in Table A-11.

TABLE A-11. PHYSICAL, CHEMICAL AND BIOLOGICAL PROPERTIES OF CADMIUM NITRATE (HAWLEY, 1977)

Molecular Formula:	$Cd(NO_3)_2$	
Molecular Weight:	236.41	
Physical Form @ 20°C:	white, amorphous pieces	
Melting Point:	350°C	
Boiling Point:	--	
Specific Gravity:	2.455	
Solubility:	Water	109 g/100 cc at 20°C
	Ammonia	soluble
	Alcohol	soluble
Biological Effects:	Rat, oral LD50: 300 mg/kg	

APPENDIX B

MONOCHLOROBENZENE DATA

This Appendix contains additional supplemental data obtained on land restoration techniques for the monochlorobenzene spill. The following data are included in this Appendix.

- background soil analyses
- pH of soils as a function of core depth and time
- percent moisture of soils as a function of core depth and time

bacterial population in the middle and lower soil layers

TABLE B-1. BACKGROUND ANALYSES OF SOILS IN MONOCHLOROBENZENE SPILL

Property Measured	Depth (cm)	High Organic Soil	Sandy-Loam	Clay Soil
pH	0.5	6.5	6.3	5.5
	5-10	6.05	6.3	4.95
	10-30	5.8	5.95	5.35
% Moisture	0-5	5.96	0.89	0.69
	5-10	0.75	1.46	0.52
	10-30	1.29	1.19	1.19
% Organic	0-5	16.56	5.25	2.63
	5-10	4.19	4.87	3.45
	10-30	0.6	0.77	0.48
Nitrate N (ppm)	0-5	0.76	0.5	0.48
	5-10	0.76	0.44	0.48
	10-30	0.6	0.77	0.48
Total Phosphorus (ppm)	0-5	60.0	13.0	19.0
Potassium (ppm)	0-5	55.0	139.0	45.0
Calcium (ppm)	0-5	624.0	1200.0	708.0
Magnesium (ppm)	0-5	57.0	120.0	107.0

TABLE B-2. pH OF HIGH ORGANIC SOIL CORE SEGMENTS - MONOCHLOROBENZENE SPILL

Depth (cm)	Initial	Days						
		1	2	8	15	22	29	41
Control								
0-5	6.5	7.9	7.8	7.7	7.7	6.5	8.9	8.3
5-10	6.05	6.9	6.3	6.7	7.5	6.2	7.3	7.3
10-30	5.8	7.4	6.3	6.9	7.0	7.4	6.7	6.8
T-1								
0-5	*	7.7	8.7	7.4	8.4	8.9	8.9	9.1
5-10	*	6.6	6.3	7.2	8.4	7.4	7.6	7.8
10-30	*	7.2	6.6	7.1	7.6	7.0	6.7	7.0
T-2								
0-5	*	7.4	7.4	8.0	8.5	7.2	8.6	8.0
5-10	*	6.8	6.3	7.9	7.9	6.9	8.2	7.3
10-30	*	6.2	6.3	7.4	7.4	6.9	7.3	6.7

TABLE B-3. pH OF SANDY-LOAM SOIL CORE SEGMENTS - MONOCHLOROBENZENE SPILL

Depth (cm)	Initial	Days 1	2	8	15	22	29	42
Control								
0-5	5.8	6.4	6.2	6.8	7.1	6.1	7.1	6.4
5-10	6.3	7.4	6.8	6.7	6.7	6.4	7.1	6.8
10-30	6.0	7.6	7.0	6.8	6.3	5.8	6.5	7.3
T-1								
0-5	*	7.1	6.8	6.9	7.5	6.8	6.9	7.0
5-10	*	6.8	6.3	7.0	7.1	6.7	6.3	6.5
10-30	*	7.3	6.7	7.1	7.2	6.9	6.8	6.5
T-2								
0-5	*	7.3	6.5	7.5	7.2	6.9	6.5	6.1
5-10	*	6.6	7.0	6.6	6.9	6.7	7.0	6.4
10-30	*	7.0	6.9	6.5	7.1	7.2	7.1	7.0

*Assumed to be similar to control

TABLE B-4. pH OF CLAY SOIL CORE SEGMENTS - MONOCHLOROBENZENE SPILL.

Depth (cm)	Initial	Days						
		1	2	8	15	22	29	42
Control								
0-5	5.5	6.2	6.1	6.4	6.2	5.7	6.0	6.2
5-10	5.0	6.4	6.2	6.0	6.2	5.6	5.9	5.8
10-30	5.4	6.2	6.5	6.2	6.6	5.2	6.6	5.6
T-1								
0-5	*	6.0	5.9	6.4	7.0	5.9	6.1	6.1
5-10	*	6.2	6.4	6.1	6.9	5.3	5.8	6.6
10-30	*	6.0	6.5	5.7	7.3	5.5	5.5	5.2
T-2								
0-5	*	6.1	6.1	5.9	6.9	6.3	5.9	6.2
5-10	*	6.3	6.4	6.2	6.7	5.7	7.6	6.2
10-30	*	6.2	5.4	6.1	6.7	6.2	6.3	6.3

* Assumed to be similar to control

TABLE B-5. PERCENT MOISTURE CONTENT HIGH ORGANIC SOIL - MONOCHLOROBENZENE SPILL

Depth (cm)	Initial	Days						
		1	2	8	15	22	29	42
Control								
0-5	9.0	24.5	35.0	10.1	-	-	13.9	11.8
5-10	11.7	17.3	36.5	11.5	12.2	14.2	9.0	5.4
10-30	11.2	16.8	13.7	13.3	9.7	22.0	15.9	3.5
T-1								
0-5	*	43.7	30.1	23.1	32.4	48.6	26.3	63.0
5-10	*	20.7	20.9	21.2	19.9	34.8	23.3	16.4
10-30	*	27.3	18.1	19.1	19.2	6.9	23.2	14.8
T-2								
0-5	*	19.8	22.9	17.4	14.8	17.7	26.0	25.3
5-10	*	18.5	16.1	19.6	14.0	10.4	22.2	11.2
10-30	*	17.8	23.7	16.2	12.1	13.5	19.3	17.1

* Assumed to be similar to control

All chambers watered after sampling on day 15 and day 29.

TABLE B-6. PERCENT MOISTURE CONTENT SANDY LOAM SOIL-MONOCHLOROBENZENE SPILL

Depth (cm)	Initial	Days 1	2	8	15	22	29	42
Control								
0-5	9.6	11.2	20.8	11.7	7.8	14.1	4.7	-
5-10	8.4	14.5	11.3	11.1	6.6	11.2	19.6	12.2
10-30	13.3	23.3	15.7	15.1	14.6	13.5	7.4	19.6
T-1								
0-5	*	13.8	13.5	11.6	11.5	27.7	14.7	20.3
5-10	*	10.9	15.4	19.3	17.8	25.6	-	21.3
10-30	*	14.2	18.8	13.0	12.3	23.1	22.3	12.4
T-2								
0-5	*	13.5	15.9	14.0	17.0	20.7	23.7	-
5-10	*	14.7	15.1	20.6	13.0	20.1	17.2	35.9
10-30	*	14.3	15.2	15.8	17.1	18.4	19.6	19.2

* Assumed to be similar to control

All chambers watered on days 15, 22, and 29 after sampling.

TABLE B-7. PERCENT MOISTURE CONTENT CLAY SOILS - MONOCHLOROBENZENE SPILL

Depth (cm)	Initial	Days 1	2	8	15	22	29	42
Control								
0-5	7.3	8.3	18.4	14.9	10.4	23.0	15.2	15.7
5-10	5.1	15.2	17.3	13.9	12.7	6.8	17.2	19.5
10-30	10.0	13.5	15.5	17.0	27.3	24.3	12.2	16.4
T-1								
0-5	*	14.4	14.0	7.7	13.0	15.2	11.8	14.8
5-10	*	8.3	12.5	13.9	14.0	16.3	13.7	16.0
10-30	*	16.6	14.3	14.5	17.8	20.1	7.4	24.4
T-2								
0-5	*	9.7	18.0	11.3	21.4	6.6	15.4	5.3
5-10	*	16.4	20.6	15.1	20.8	31.6	16.0	17.5
10-30	*	13.6	19.3	7.7	14.9	-	29.0	9.9

* Assumed to be similar to control

All chambers watered on days 15, 22 and 29 after sampling.

TABLE B-8. PERCENT ORGANIC CONTENT HIGH ORGANIC SOIL - MONOCHLOROBENZENE SPILL

Depth (cm)	Initial	Days 1	2	8	15	22	29	36
Control								
0-5	16.6	15.6	17.4	13.0	10.5	-	16.1	17.7
5-10	4.2	5.5	5.4	3.9	4.2	5.1	5.8	8.3
10-30	2.9	4.8	4.6	4.8	4.1	11.5	5.5	2.1
T-1								
0-5	*	14.8	17.8	12.7	15.7	28.7	12.2	54.3
5-10	*	3.4	5.5	4.2	3.3	6.2	6.5	4.0
10-30	*	7.6	4.6	3.8	-	4.3	5.6	4.0
T-2								
0-5	*	7.1	9.6	12.7	12.0	10.4	17.0	10.2
5-10	*	4.3	4.2	2.4	3.7	4.8	27.0	4.4
10-30	*	4.2	4.1	4.2	4.9	4.8	-	4.0

* Assumed to be the same as control

TABLE B-9. PERCENT ORGANIC CONTENT SANDY SOIL - MONOCHLOROBENZENE SPILL

Depth (cm)	Initial	Days						
		1	2	8	15	22	29	36
Control								
0-5	5.3	4.2	4.5	6.1	6.9	5.4	6.7	5.9
5-10	4.9	5.0	8.1	3.4	7.2	4.5	6.8	4.7
10-30	4.7	2.6	5.7	3.1	4.7	6.6	6.0	4.8
T-1								
0-5	*	5.2	4.9	6.1	7.0	6.5	6.7	5.0
5-10	*	3.9	5.6	11.4	2.2	5.4	5.6	4.2
10-30	*	4.4	6.4	5.2	0.4	5.5	7.0	5.6
T-2								
0-5	*	4.0	6.2	6.2	7.0	6.7	5.9	4.5
5-10	*	5.2	5.3	4.6	2.9	6.4	7.1	4.1
10-30	*	4.9	5.6	4.9	3.4	4.9	7.0	6.2

* Assumed to be similar to control

TABLE B-10. PERCENT ORGANIC CONTENT CLAY SOIL - MONOCHLOROBENZENE SPILL

Depth (cm)	Initial	Days 1	2	8	15	22	29	36
Control								
0-5	2.6	1.5	2.7	2.3	3.0	2.9	4.3	3.7
5-10	3.5	1.5	2.3	2.2	-	4.4	4.3	2.0
10-30	4.7	1.8	2.4	6.8	3.0	3.9	4.1	3.0
T-1								
0-5	*	-	2.5	4.5	2.8	3.7	4.9	1.8
5-10	*	-	1.9	1.9	2.2	3.8	4.6	3.5
10-30	*	-	2.7	1.9	3.5	3.6	4.2	3.0
T-2								
0-5	*	3.1	2.9	3.6	3.0	5.4	4.8	1.7
5-10	*	3.0	3.8	4.5	-	3.6	4.9	0.1
10-30	*	3.0	5.5	11.4	-	4.5	4.5	2.0

* Assumed to be similar to control

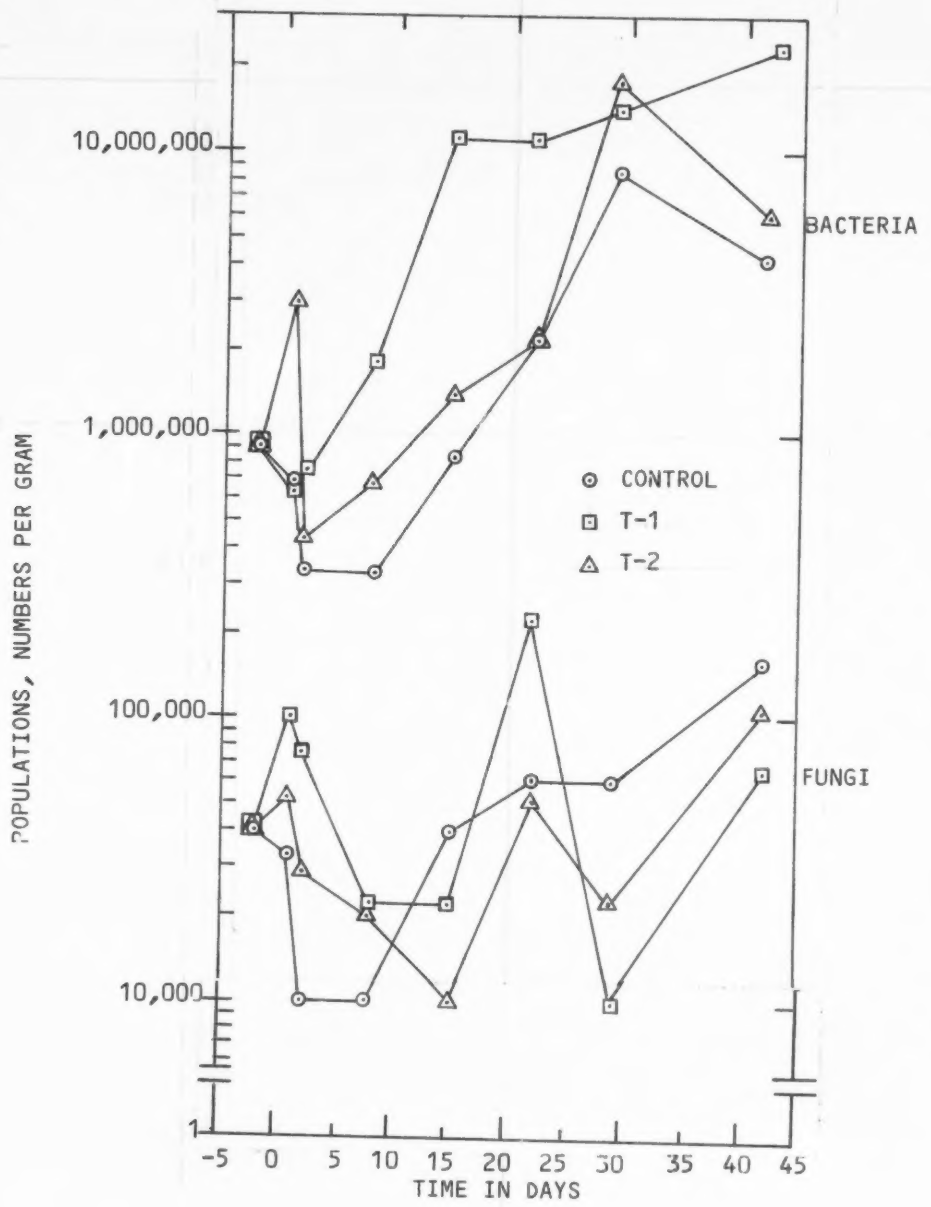


Figure B-1. Middle level (5-10 cm) high organic soil microbial population - monochlorobenzene spill.

BEGIN FIRST LINE OF TEXT HERE
TYPING GUIDE SHEET
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD BEGIN SECTIONS HERE

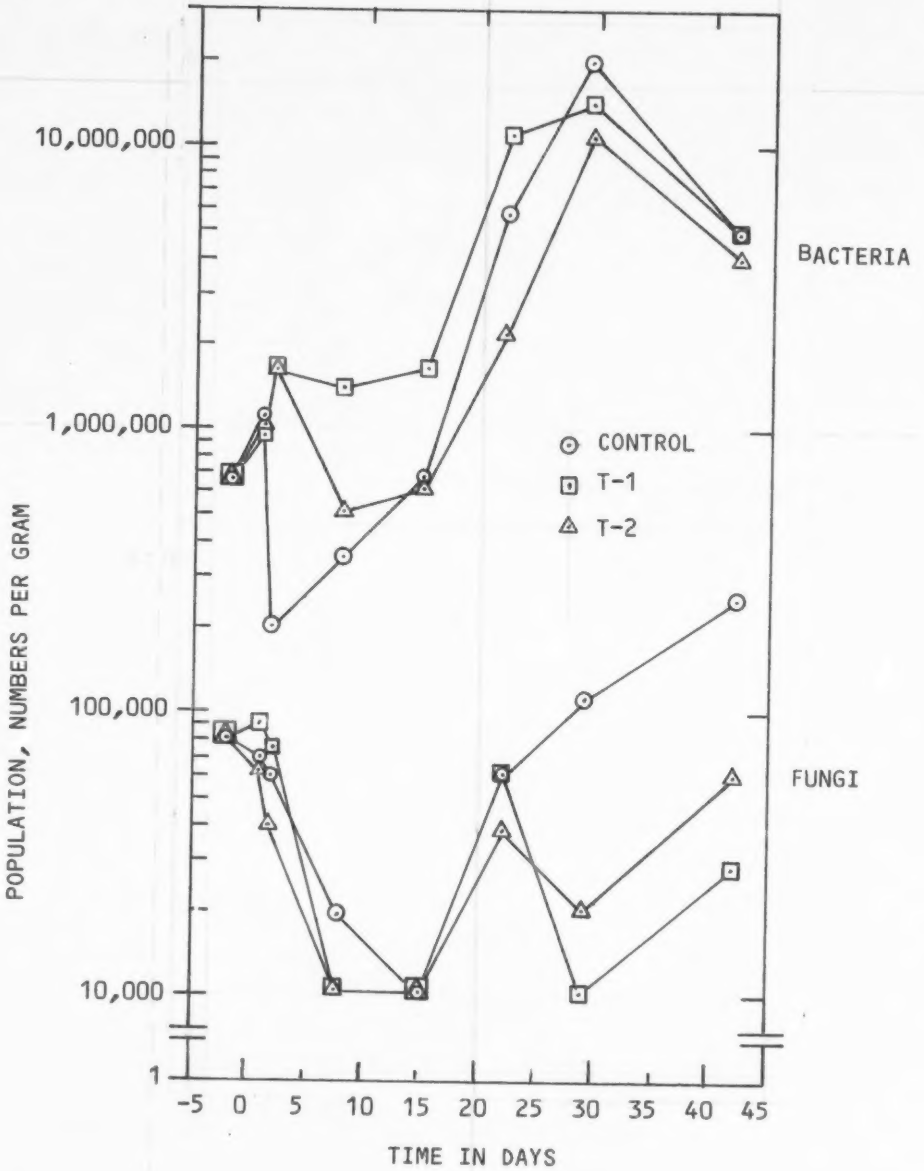


Figure B-2. Bottom level (10-30 cm) high organic soil microbial population - monochlorobenzene spill.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
PAGE NUMBER
EPA-287 (Cin.)
(3-76)

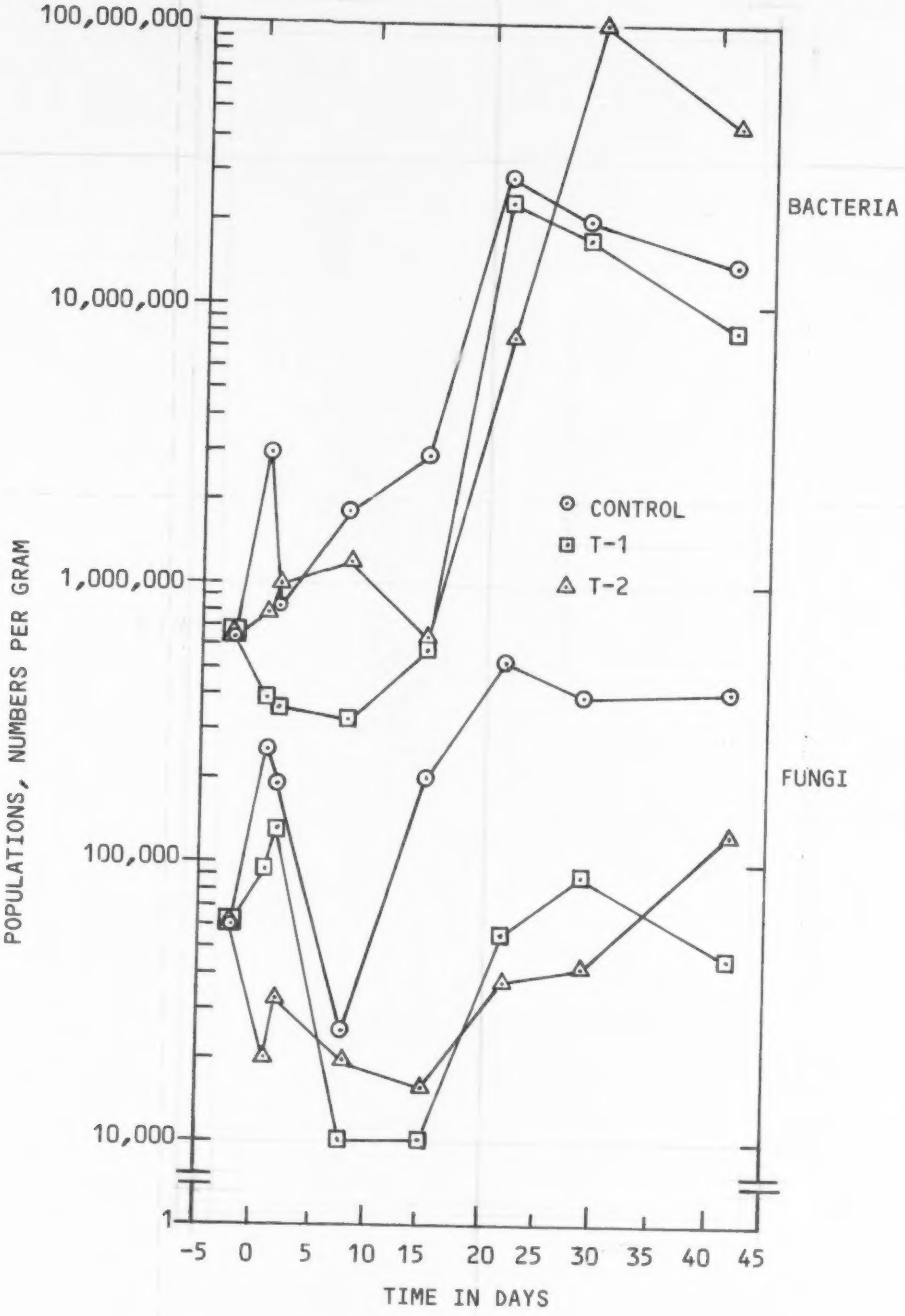


Figure B-3. Middle level (5-10 cm) sandy-loam soil microbial population - monochlorobenzene spill.

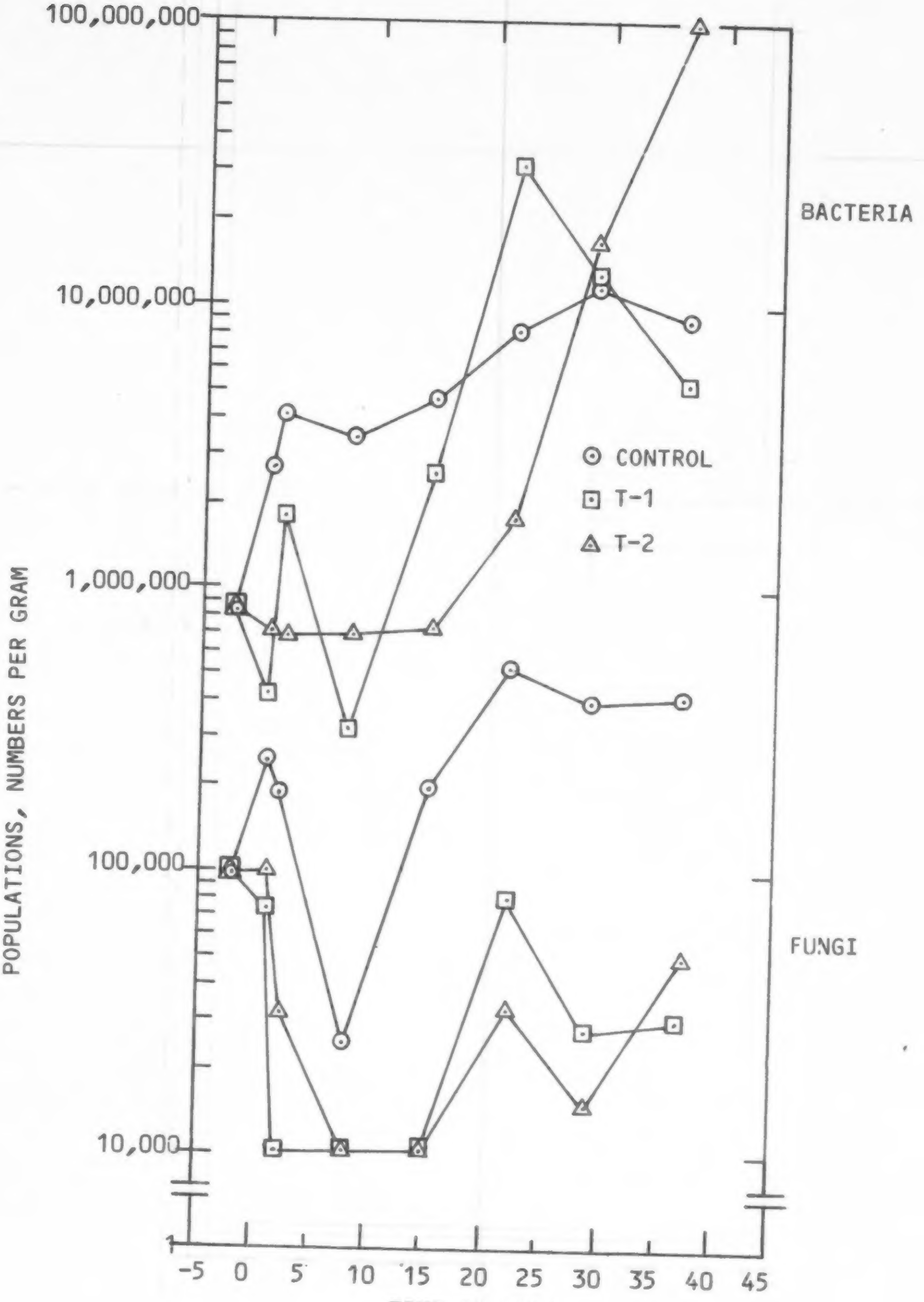


Figure B-4. Bottom level (10-30 cm) sandy-loam soil microbial population - monochlorobenzene spill.

BEGIN FIRST LINE OF TEXT HERE
TYPING GUIDE SHEET
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD BEGIN SECTIONS HERE

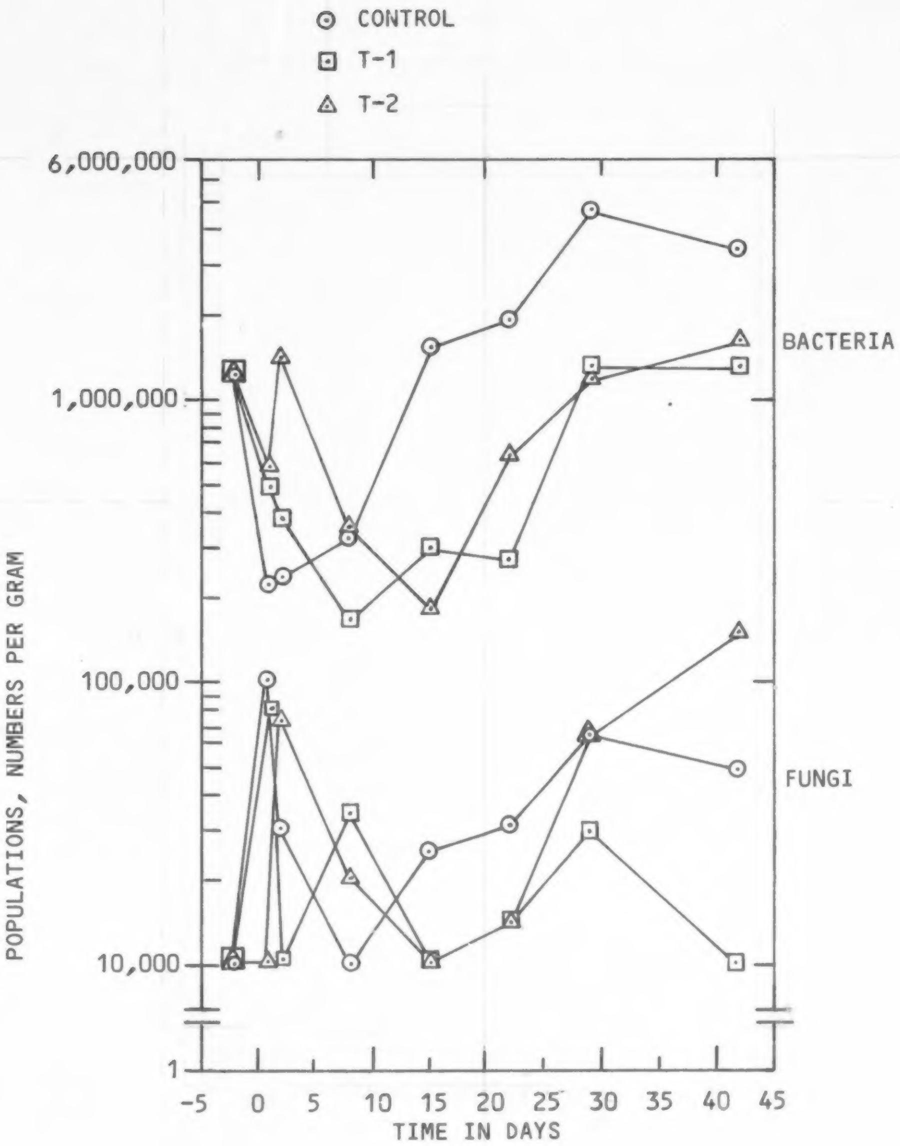


Figure B-5. Middle level (5-10 cm) clay soil microbial population - monochlorobenzene spill.

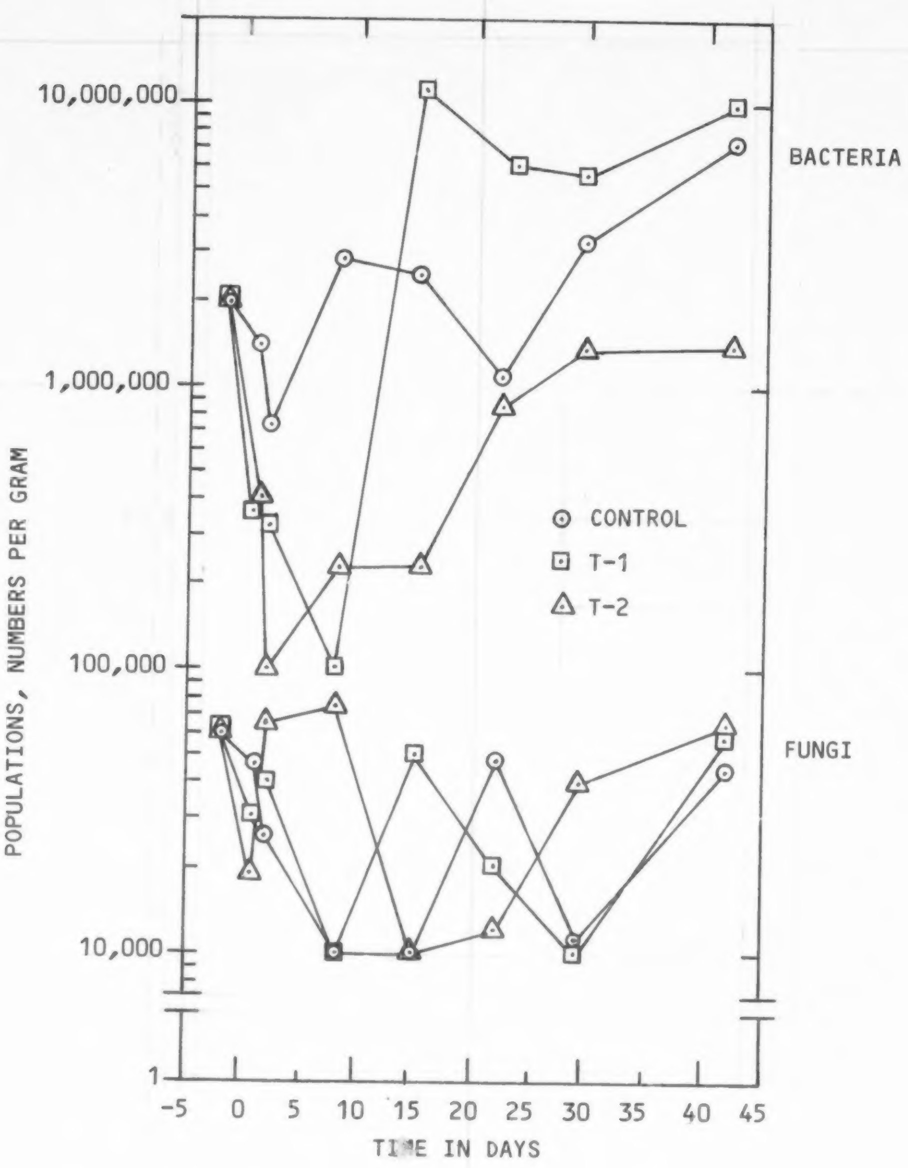


Figure B-6. Bottom level (10-30 cm) clay soil microbial population - monochlorobenzene spill.

APPENDIX C

ETHION DATA

This appendix contains additional supplemental data obtained on land restoration techniques for an Ethion spill. The following data are included in this Appendix.

- background soil analyses
- pH of soils as a function of core depth and time
- percent moisture of soils as a function of core depth and time
- bacterial populations in the middle and lower soil layers
- ^{14}C radiation levels

TABLE C-1. BACKGROUND ANALYSES OF SOILS - ETHION SPILL

Property Measured	Depth (cm)	High Organic Soil	Sandy-Loam	Clay Soil
pH	0-5	7.3	6.5	6.35
	5-10	7.6	6.7	6.4
	10-30	6.7	7.0	6.3
% Moisture	0-5	9.6	7.3	9.0
	5-10	8.4	5.1	11.7
	10-30	13.3	10.0	11.3
% Organic	0-5	7.6	5.1	1.9
	5-10	3.9	5.0	2.2
	10-30	3.2	4.2	2.0
Nitrate N (ppm)	0-5	0.3	2.5	0.7
	5-10	0.3	0.3	0.3
	10-30	0.7	0.3	0.3
Organic Phosphorus (ppm)	0-5	1.0	1.0	1.2
	5-10	0.7	1.0	.7
	10-30	3.0	3.0	.1
Total Phosphorus (ppm)	0-5	60	13	19
Potassium (ppm)	0-5	55	139	45
Calcium (ppm)	0-5	624	1200	708
Magnesium (ppm)	0-5	57	120	107

TABLE C-2. pH OF ORGANIC SOILS CORE SEGMENTS - ETHION SPILL

Depth (cm)	Initial	1	2	9	16	23	30	17	44	52	59	65
Control												
0-5	7.3	4.7	5.9	6.5	5.05	6.25	6.05	5.25	3.85	5.2	5.4	5.9
5-10	7.6	6.0	5.2	4.75	4.15	5.45	5.8	5.6	4.45	5.4	5.9	4.5
10-30	6.7	4.4	6.4	5.1	4.45	5.45	5.8	5.85	4.95	4.7	5.85	4.6
T-1												
0-5	*	5.2	5.1	6.05	6.05	6.1	6.2	5.56	4.25	6.3	6.0	6.6
5-10	*	5.1	4.7	5.25	4.75	6.75	5.95	4.75	4.4	5.3	6.4	6.2
10-30	*	6.1	4.65	4.5	4.35	5.85	4.85	4.45	6.2	4.85	5.7	5.3
T-2												
0-5	*	6.2	5.7	6.6	6.3	6.05	5.75	6.15	4.25	6.2	6.8	7.2
5-10	*	5.5	4.7	5.05	6.05	4.45	6.15	6.0	4.5	4.9	5.6	6.7
10-30	*	6.6	5.05	5.25	5.75	4.8	4.4	5.35	6.05	5.4	6.6	5.0

* Assumed same as control

(continued)

TABLE C-2 (continued)

Depth (cm)	72	79	86	93	101	108	113	121	127	136	142
Control											
0-5	5.7	5.3	5.2	5.15	5.45	4.8	5.1	4.7	4.3	5.1	5.5
5-10	5.4	5.2	5.0	5.25	5.0	5.0	4.95	4.7	4.1	5.4	5.45
10-30	5.2	5.2	5.0	5.0	5.0	4.6	4.85	4.9	4.0	5.0	5.2
T-1											
0-5	5.7	7.3	5.2	5.15	5.45	4.8	5.8	5.9	4.65	5.7	5.5
5-10	5.4	5.2	5.0	5.25	5.0	5.0	4.9	4.8	4.60	4.45	5.2
10-30	5.2	5.2	5.0	5.0	5.0	4.6	5.0	5.15	4.3	4.45	4.7
T-2											
0-5	6.5	7.1	6.85	6.3	6.45	6.1	6.45	6.0	5.5	5.85	6.15
5-10	5.5	5.25	5.8	5.25	5.2	4.6	5.3	4.9	4.85	5.3	5.25
10-30	5.7	5.2	5.8	5.1	5.0	4.8	4.9	4.8	4.45	4.7	4.55

(continued)

TABLE C-2 (continued)

Depth (cm)	155	158	183	186	205	210	212	219	221	228	238	249	256
Control													
0-5	5.15	4.7	4.8	5.3	5.25	5.5	4.8	4.9	4.9	5.4	5.2	5.1	5.2
5-10	5.1	4.6	4.8	4.95	5.29	5.3	4.7	4.8	-	5.9	5.1	5.0	5.2
10-30	5.0	4.5	4.9	5.0	-	-	-	4.7	-	-	5.1	5.0	5.05
T-1													
0-5	6.1	6.2	7.9	9.8	10.30	10.4	9.9	8.6	9.6	9.8	9.75	10.3	10.2
5-10	5.6	4.8	6.9	7.1	10.40	10.5	10.3	6.3	-	8.2	9.2	10.3	9.1
10-30	5.05	4.7	5.4	5.5	-	-	-	5.5	-	-	10.2	9.45	9.1
T-2													
0-5	6.0	5.8	6.3	5.7	6.80	6.6	11.2	12.5	11.5	10.6	11.7	10.7	12.4
5-10	5.6	5.4	5.85	5.1	5.30	5.3	8.1	10.8	-	9.9	10.75	10.4	10.6
10-30	5.2	5.3	5.1	4.8	-	-	-	7.5	-	-	11.8	9.8	6.4

TABLE C-3. pH OF SANDY SOILS CORE SEGMENTS - ETHION SPILL

Depth (cm)	Initial	1	2	9	16	23	30	37	44	52	59	65
Control												
0-5	6.7	4.5	4.7	4.95	3.85	4.35	4.0	4.35	4.95	5.0	5.25	4.7
5-10	7.0	4.0	4.3	4.5	5.25	4.35	3.95	5.6	5.05	5.8	6.0	6.0
10-30	7.0	4.0	4.3	4.5	5.25	4.35	3.95	5.5	5.05	5.8	6.0	6.0
T-1												
0-5	*	3.8	4.25	3.35	3.8	5.95	3.75	4.3	3.8	4.7	6.1	6.1
5-10	*	5.4	4.65	5.8	5.1	5.85	3.85	4.25	4.3	5.1	5.85	5.6
10-30	*	5.3	5.45	5.9	5.1	4.1	4.45	4.25	5.0	5.8	6.8	5.8
T-2												
0-5	*	4.3	4.7	4.45	4.65	4.15	3.8	4.8	-	5.4	5.6	6.0
5-10	*	4.8	4.8	5.15	4.95	4.65	3.75	5.65	4.55	5.3	6.0	6.1
10-30	*	5.5	5.9	5.45	4.65	4.05	4.45	5.25	5.35	4.4	5.7	6.1

*assumed same as control

(continued)

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 287)
TYPING GUIDE SHEET

TABLE C-3 (continued)

Depth (cm)	72	79	86	93	101	108	113	121	127	136	142
Control											
0-5	5.4	5.3	3.35	4.6	4.5	4.35	4.8	4.4	4.0	4.3	4.35
5-10	5.4	4.75	5.4	4.8	4.8	5.0	5.15	4.6	4.4	4.2	4.55
10-30	5.6	5.1	5.6	5.1	4.8	4.6	4.4	5.1	4.65	4.6	4.7
T-1											
0-5	7.1	6.1	6.4	5.7	6.1	5.9	5.9	6.1	4.6	4.75	5.35
5-10	6.9	6.1	6.25	5.6	6.15	5.4	5.4	5.5	5.0	4.8	5.1
10-30	6.4	5.5	5.4	5.25	5.5	4.7	5.7	5.3	5.35	4.8	5.1
T-2											
0-5	7.3	7.0	6.3	6.3	6.5	6.0	5.65	6.0	6.45	5.7	5.3
5-10	6.6	6.6	5.95	6.0	5.9	6.0	5.95	5.3	5.4	5.0	5.45
10-30	5.8	5.3	5.3	5.0	4.9	5.2	5.0	5.1	5.0	5.1	4.8

(continued)

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 287)
TYPING GUIDE SHEET

TABLE C-3 (continued)

Depth (cm)	155	158	183	186	205	210	212	219	221	228	238	256
Control												
0-5	4.35	4.0	4.3	4.1	4.80	4.6	4.2	4.5	4.5	4.8	4.7	4.7
5-10	4.7	4.15	4.7	4.4	4.90	5.15	4.5	5.3	-	6.0	5.7	5.3
10-30	4.95	5.2	4.9	5.1	-	-	-	5.4	-	-	5.6	5.3
T-2												
0-5	5.4	7.4	8.3	8.3	10.11	10.5	10.0	10.4	10.3	10.2	10.7	10.6
5-10	5.8	6.2	5.9	6.4	10.40	10.4	10.0	9.45	-	8.7	10.6	10.5
10-30	5.6	5.5	6.1	5.65	-	-	-	6.2	-	-	9.2	10.1
T-2												
0-5	6.3	5.95	6.7	6.3	6.65	5.9	10.8	11.4	10.8	10.5	11.1	11.0
5-10	6.25	5.7	5.9	6.6	5.70	6.7	9.9	10.55	-	10.1	10.75	10.3
10-30	5.2	5.3	5.3	6.25	-	-	-	8.5	-	-	9.3	5.9

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 287)
© U.S. GOVERNMENT PRINTING OFFICE 1980-680-038
TYPING GUIDE SHEET

TABLE C-4. pH OF CLAY SOILS CORE SEGMENTS - ETHION SPILL

Depth (cm)	Initial	1	2	9	16	23	30	37	44	52	59	65
Control												
0-5	6.4	4.1	4.5	3.75	4.25	4.0	3.85	3.7	5.85	4.1	--	4.7
5-10	6.4	4.3	4.25	3.85	4.35	4.0	4.0	4.4	5.85	4.3	5.0	4.6
10-30	6.3	4.3	4.35	5.55	3.8	4.8	4.45	5.95	5.0	6.4	4.4	5.0
T-2												
0-5	*	3.8	4.5	3.7	4.35	3.85	4.1	3.75	7.0	5.4	6.5	6.4
5-10	*	4.1	4.3	4.25	3.9	4.0	5.7	4.1	5.85	4.9	5.3	5.3
10-30	*	4.3	4.5	4.95	4.35	4.25	4.3	4.2	5.7	4.7	5.6	5.2
T-2												
0-5	*	4.3	3.85	4.15	4.15	3.9	3.85	3.9	6.45	4.8	5.75	6.0
5-10	*	4.3	4.25	4.45	4.25	3.9	4.0	4.2	4.65	4.1	5.6	4.8
10-30	*	4.3	4.8	5.0	4.65	5.35	4.15	4.2	6.45	4.3	5.5	4.8

(continued)

TABLE C-4 (continued)

Depth (cm)	72	79	86	93	101	108	113	121	127	136	142
Control											
0-5	4.75	4.2	4.9	4.5	3.9	3.4	4.45	3.8	3.4	3.2	3.65
5-10	4.9	4.65	5.0	4.1	4.0	3.8	4.8	3.5	4.0	2.95	3.7
10-30	4.95	5.9	5.65	4.5	5.0	4.2	6.4	4.85	5.0	-	4.7
T-2											
0-5	5.9	6.6	6.4	5.95	6.1	4.7	6.85	6.2	5.2	5.2	4.3
5-10	5.1	5.25	5.9	4.9	5.9	4.8	6.45	5.6	5.1	4.5	3.8
10-30	4.75	4.4	6.1	5.4	5.4	5.7	5.6	4.9	5.15	4.0	4.65
T-2											
0-5	6.8	6.0	6.5	6.5	6.0	5.5	6.2	5.8	5.25	6.25	5.3
5-10	5.8	5.0	4.45	5.5	4.6	4.3	4.65	5.0	4.4	4.4	4.5
10-30	6.0	5.5	4.95	4.9	5.4	4.5	5.4	5.4	4.7	4.3	4.8

(continued)

TABLE C-4 (continued)

Depth (cm)	155	158	183	186	205	210	212	219	221	228	238	249	256
Control													
0-5	3.35	3.55	3.5	3.5	4.10	4.3	4.4	3.85	3.8	4.1	4.3	5.2	4.1
5-10	4.25	3.6	3.5	3.3	3.95	3.8	4.1	4.1	-	4.6	4.45	4.8	4.2
10-30	5.0	4.8	5.4	4.0	-	-	-	4.05	-	-	4.35	5.85	4.75
T-1													
0-5	6.5	9.7	9.9	10.0	10.71	10.8	10.9	10.6	10.6	10.6	10.6	10.2	10.6
5-10	6.2	5.0	9.5	10.0	10.50	10.35	10.5	10.6	-	10.7	10.4	10.3	10.85
10-30	6.15	4.5	6.7	10.2	-	-	-	10.55	-	-	7.85	8.8	10.6
T-2													
0-5	5.4	5.5	5.3	6.6	5.80	5.9	10.15	10.7	10.5	10.0	10.9	10.5	10.9
5-10	-	4.0	5.1	5.6	4.40	4.7	9.1	10.6	-	10.3	10.6	10.45	10.8
10-30	-	4.35	4.65	5.05	-	-	-	10.9	-	-	10.8	10.4	10.7

TABLE C-5. PERCENT MOISTURE IN ORGANIC SOILS - ETHION SPILL

Depth (cm)	Initial	1	2	9	16	23	30	37	44	52	59	65
Control												
0-5	9.6	13.27	12.39	9.16	16.26	--	35.84	28.22	6.6	17.10	23.4	14.07
5-10	8.4	7.20	11.68	4.96	11.76	--	--	--	7.15	18.61	15.1	28.13
10-30	13.3	4.24	15.30	3.20	19.14	20.84	18.54	14.37	9.14	14.68	--	--
T-2												
0-5	*	20.06	14.29	13.94	16.05	36.13	42.12	18.07	20.78	14.58	14.1	15.86
5-10	*	2.87	15.21	17.95	11.19	16.11	6.50	27.59	21.04	5.33	18.7	16.81
10-30	*	5.08	15.96	14.31	15.85	15.18	--	13.71	14.32	19.58	14.3	9.11
T-2												
0-5	*	19.78	22.49	36.49	22.23	17.81	17.62	22.39	15.94	12.04	22.9	25.02
5-10	*	3.77	10.54	18.65	7.83	24.10	22.68	15.37	16.98	29.38	18.5	19.55
10-30	*	4.20	12.81	15.40	14.05	11.33	21.21	15.84	10.97	22.29	15.8	16.25
				↑	↑		↑		↑	↑		

(continued)

↑ chambers watered

TABLE C-5. (continued)

Depth (cm)	72	79	86	93	Days 101	108	113	121	127	136	142
Control											
0.5	10.25	16.04	8.54	12.94	24.40	15.10	23.24	13.44	28.3	17.0	--
5-10	5.42	12.67	14.51	14.78	16.92	14.33	16.83	13.13	18.0	16.8	17.4
10-30	24.98	15.09	15.07	15.74	17.71	14.16	19.08	15.59	17.1	16.2	16.4
T-1											
0.5	16.11	19.84	21.82	19.91	22.47	26.52	14.81	19.72	20.24	24.9	--
5-10	16.74	22.38	19.77	18.64	22.51	23.53	21.04	19.94	18.4	21.6	20.8
10-30	20.00	15.58	16.05	19.80	20.90	19.71	18.67	27.39	37.8	21.1	20.13
T-2											
0-5	22.66	27.09	24.33	26.92	23.82	35.51	23.55	23.89	23.0	30.7	--
5-10	15.45	18.09	18.35	22.26	18.45	20.15	22.20	20.06	20.2	21.7	20.1
10-30	18.02	20.75	18.22	20.81	16.93	28.34	21.48	20.36	19.2	19.4	19.6
				†			†		†		

(continued)

† chambers watered

TABLE C-5 (continued)

Depth (cm)	Days											
	155	158	183	186	205	210	212	219	221	228	238	256
Control												
0-5	16.38	15.40	30.00	18.29	16.07	20.56	18.42	22.14	24.62	15.75	16.63	16.43
5-10	15.34	15.75	18.71	15.09	19.30	17.99	17.80	--	21.51	16.39	21.91	15.69
10-30	17.75	16.62	25.56	17.11	--	--	20.02	--	--	16.05	14.14	13.98
T-1												
0-5	21.42	23.52	32.18	29.51	24.52	26.22	22.79	25.82	25.09	--	21.67	23.88
5-10	25.30	20.11	28.76	23.19	23.80	25.49	27.26	--	23.21	19.66	26.74	18.57
10-30	21.07	36.93	20.08	22.31	--	--	27.15	--	--	23.44	23.80	21.04
T-2												
0-5	26.42	24.80	--	24.85	26.63	27.42	31.22	28.02	36.47	25.66	21.93	34.96
5-10	19.52	20.55	20.13	20.07	19.98	23.59	22.22	--	25.54	22.22	18.98	23.50
10-30	43.21	21.05	21.61	20.06	--	--	22.47	--	--	24.12	22.90	19.02
	†	†										

†chambers watered

TABLE C-6. PERCENT MOISTURE IN SANDY SOILS - ETHION SPILL

Depth (cm)	Initial	Days 1	2	9	16	23	30	37	44	52	59	65
Control												
0-5	7.3	—	7.25	9.84	10.00	10.74	21.95	12.53	17.32	22.92	20.2	14.59
5-10	5.1	8.14	26.86	22.79	1.88	16.75	4.90	9.47	18.93	23.10	18.8	—
10-30	10.0	7.41	17.04	5.04	15.20	16.42	15.14	15.90	6.07	18.04	17.1	14.16
T-1												
0-5	*	—	9.38	13.63	9.33	—	12.44	24.98	9.94	15.82	8.8	16.00
5-10	*	8.11	9.17	11.00	8.05	12.96	10.08	20.83	14.62	17.84	20.3	17.55
10-30	*	5.87	13.78	16.07	8.05	16.23	15.32	12.74	15.87	18.24	19.0	15.60
T-2												
0-5	*	—	5.61	12.32	22.61	12.39	15.15	9.38	14.58	16.76	20.1	8.76
5-10	*	13.63	5.63	7.40	—	2.47	13.80	18.44	5.10	9.81	17.2	11.07
10-30	*	10.17	4.18	11.09	20.32	12.25	18.41	13.56	10.12	18.4	20.00	21.71
				†	†		†		†	†		†

(continued)

* Assumed same as control

† chambers watered

TABLE C-6 (continued)

Depth (cm)	Days 72	79	86	93	101	108	113	121	127	136	142
Control											
0-5	15.48	17.60	12.78	38.46	17.99	16.80	21.21	13.78	14.7	17.6	--
5-10	17.37	13.79	18.87	18.75	15.97	19.80	20.26	17.80	16.7	21.8	20.5
10-30	18.66	16.97	14.61	16.17	6.40	18.60	15.40	19.82	18.6	19.44	19.7
T-1											
0-5	18.52	14.75	12.76	19.09	14.58	19.50	10.49	22.62	22.8	18.5	--
5-10	14.93	18.25	18.08	20.12	20.55	13.63	12.24	22.24	22.7	21.0	22.7
10-30	17.71	21.64	19.14	20.51	19.17	20.30	19.16	23.23	18.4	22.1	23.1
T-2											
0-5	16.09	20.93	16.45	19.41	20.63	--	16.05	32.32	18.3	19.38	--
5-10	18.46	18.56	20.43	17.56	19.00	21.59	18.09	28.71	21.4	21.05	21.9
10-30	17.64	19.16	21.44	15.45	24.42	21.00	20.14	16.86	24.6	25.7	22.3
			†			†		†			

(continued)

* Assumed same as control

† chambers watered

TABLE C-6. (continued)

Depth (cm)	155	158	183	186	205	Days 210	212	219	221	228	238	249
Control												
0-5	15.64	--	12.03	15.62	16.31	15.10	14.31	13.51	13.68	10.89	10.03	16.28
5-10	18.56	--	16.36	17.18	18.97	16.50	16.67	--	17.82	13.75	13.64	31.74
10-30	--	--	19.06	21.39	--	--	19.11	--	--	16.65	17.60	15.79
T-1												
0-5	23.92	20.47	18.15	17.18	20.14	20.30	16.28	17.02	19.13	17.20	25.03	10.83
5-10	20.82	22.16	19.35	24.67	22.30	23.93	29.07	--	25.06	19.98	23.48	19.97
10-30	23.79	23.27	25.00	26.58	--	--	24.87	--	--	30.06	26.58	24.40
T-2												
0-5	19.23	16.39	21.36	18.76	21.30	21.54	23.82	23.57	21.10	21.72	23.63	18.78
5-10	29.27	17.12	22.07	22.17	17.44	24.01	27.45	--	24.57	--	21.99	20.35
10-30	22.43	20.45	24.11	22.89	--	--	26.21	--	--	23.23	24.99	22.08
	†	†										

* Assumed same as control

† chambers watered

TABLE C-7. PERCENT MOISTURE IN CLAY SOILS - ETHION SPILL

Depth (cm)	Initial	Days 1	2	9	16	23	30	37	44	52	59	65
Control												
0-5	9.0	--	9.45	7.12	13.70	9.17	15.63	15.05	5.9	13.64	17.0	15.36
5-10	11.7	5.05	16.00	11.45	17.10	16.59	10.10	15.65	8.6	8.88	16.6	13.15
10-30	11.3	4.26	13.76	6.33	17.10	3.77	13.35	9.15	14.33	13.65	13.3	17.00
T-1												
0-5	*	13.95	10.60	13.22	9.66	6.67	4.09	7.95	3.7	10.65	12.6	15.84
5-10	*	4.70	3.63	12.08	16.05	19.15	15.94	11.12	13.25	10.61	15.0	9.11
10-30	*	4.99	14.15	11.09	11.87	3.93	8.38	14.17	17.25	13.02	13.8	12.99
T-2												
0-5	*	11.01	11.06	--	3.21	15.80	--	22.29	12.5	14.00	15.9	16.56
5-10	*	5.52	7.79	7.84	7.41	14.29	11.13	12.00	15.49	6.29	13.0	13.11
10-30	*	4.58	12.27	13.83	8.76	18.62	--	18.16	10.44	10.88	13.1	12.15
				†	†		†		†	†		†

* Assumed same as control

† chambers watered

(continued)

TABLE C-7 (continued)

Depth (cm)	72	79	86	93	101	Days 108	113	121	127	136	142
Control											
0-5	16.60	14.68	14.59	14.92	13.78	13.60	13.85	17.77	15.7	15.7	--
5-10	15.34	16.21	13.15	14.92	14.20	13.05	14.20	16.48	16.1	16.09	15.5
10-30	17.14	15.53	24.24	17.53	17.78	14.86	16.47	19.31	16.7	17.5	15.64
T-1											
0-5	12.18	10.89	6.68	15.15	11.44	11.51	10.87	21.33	11.3	12.5	--
5-10	14.72	17.01	34.91	12.82	15.64	10.54	12.28	15.86	14.0	15.1	12.6
10-30	14.55	18.65	17.74	16.00	16.40	15.08	12.47	35.91	14.4	14.6	13.8
T-2											
0-5	14.68	16.82	11.56	13.64	16.27	18.08	14.99	15.59	12.9	18.7	--
5-10	11.94	10.88	10.62	14.54	13.93	16.35	14.28	17.91	14.2	15.2	18.4
10-30	15.27	15.28	--	14.89	14.34	17.14	14.79	18.35	15.1	19.4	14.5
			†			†		†			

†chambers watered

(continued)

TABLE C-7 (continued)

Depth (cm)	Days 155	158	183	186	205	210	212	219	221	228	238	249
Control												
0-5	14.29	13.22	24.28	13.73	16.00	17.43	15.63	15.42	16.64	14.00	13.50	12.71
5-10	17.00	13.10	15.79	16.39	18.11	18.90	15.14	--	16.64	13.81	14.08	12.67
10-30	16.19	19.92	16.54	15.67	--	--	14.83	--	--	13.62	15.49	14.96
T-1												
0-5	--	30.33	12.02	13.74	15.91	15.33	11.36	17.13	15.24	8.41	10.60	11.47
5-10	--	26.75	15.79	21.89	15.52	15.74	24.70	--	16.90	12.85	12.95	13.33
10-30	--	29.24	11.24	21.20	--	--	17.76	--	--	15.08	12.86	14.39
T-2												
0-5	19.35	15.70	25.43	12.89	16.13	16.13	17.33	18.14	16.36	13.73	21.63	9.89
5-10	16.70	13.34	5.79	7.85	16.72	16.81	17.76	--	17.27	12.81	14.04	11.93
10-30	16.31	15.53	16.05	14.93	--	--	17.02	--	--	18.26	14.29	14.36
	↑	↑										

↑ chambers watered

A. T-1 AND T-2, NUTRIENT BROTH, T-2 PLOWED
B. T-1 AND T-2, LIMED, T-2 PLOWED
C. T-1 AND T-2, LIMED AND NUTRIENT BROTH
D. T-1 AND T-2, NUTRIENT BROTH AND TWEEN 80
E. T-1 AND T-2, ETHANOL-WATER SOLUTION
F. T-2, ETHANOL-NaOH SOLUTION

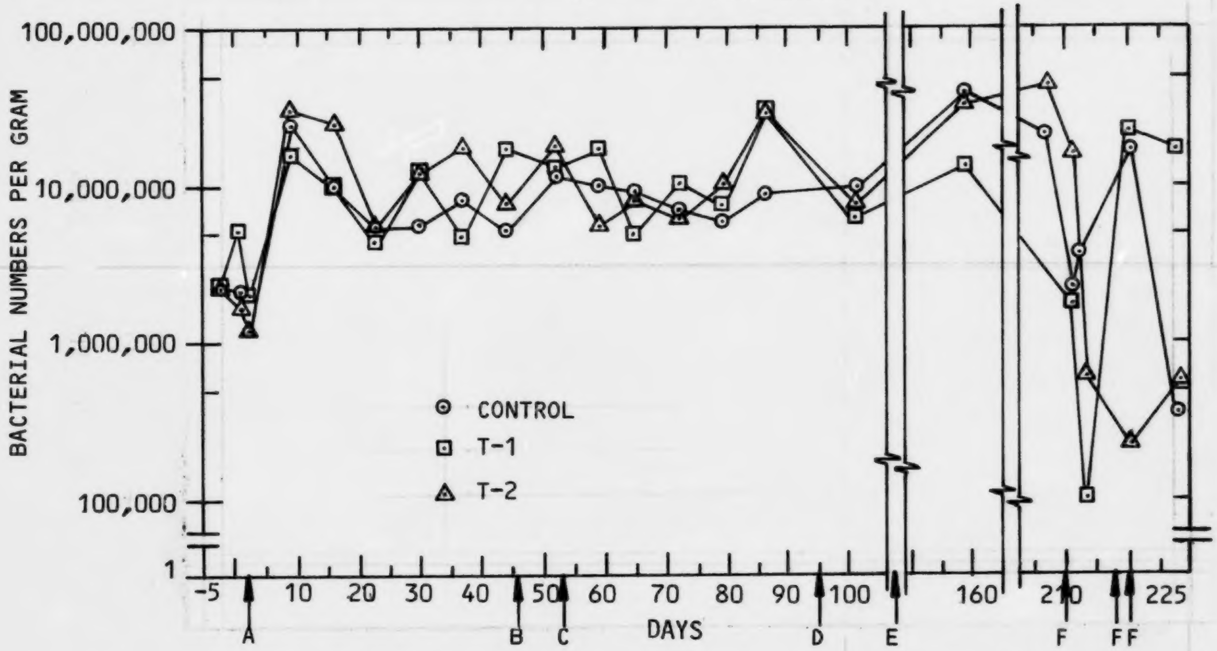


Figure C-1. Middle level organic soil bacterial populations - Ethion spill.

EPA-287 (Cin.)
(4-76)

A. T-1 AND T-2, NUTRIENT BROTH, T-2 PLOWED
B. T-1 AND T-2, LIMED, T-2 PLOWED
C. T-1 AND T-2, LIMED AND NUTRIENT BROTH
D. T-1 AND T-2, NUTRIENT BROTH AND TWEEN 80
E. T-1 AND T-2, ETHANOL-WATER SOLUTION
F. T-2, ETHANOL-NaOH SOLUTION

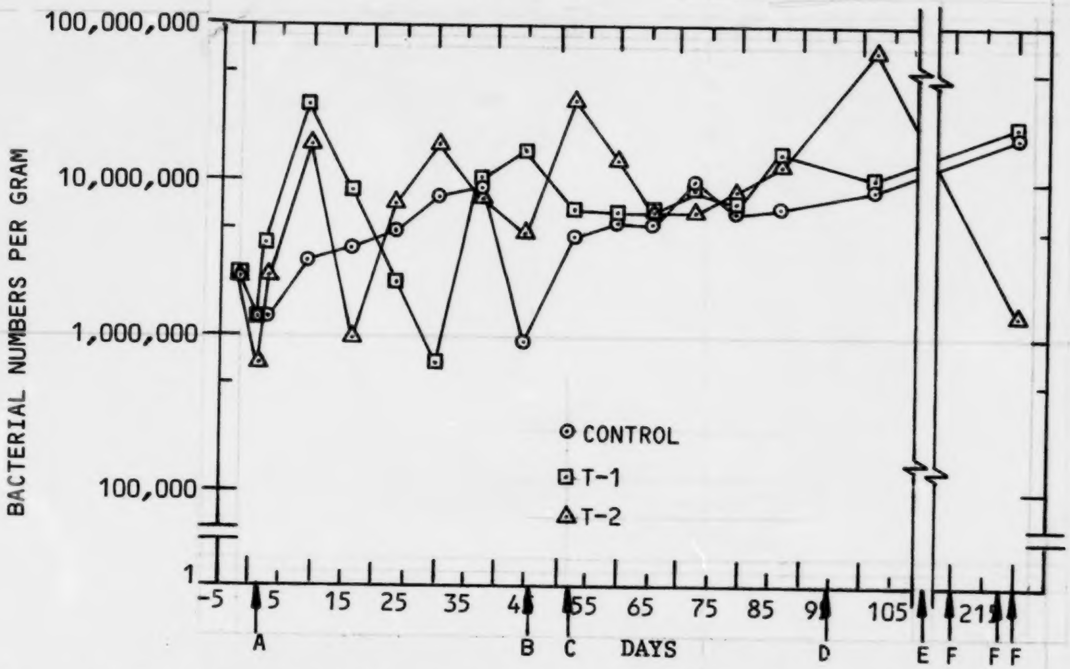


Figure C-2. Lower level organic soil bacterial population - Ethion spill.

EPA-287 (Cin.)
(4-76)

A. T-1 AND T-2, NUTRIENT BROTH, T-2 PLOWED
B. T-1 AND T-2, LIMED, T-2 PLOWED
C. T-1 AND T-2, LIMED AND NUTRIENT BROTH
D. T-1 AND T-2, NUTRIENT BROTH AND TWEEN 80
E. T-1 AND T-2, ETHANOL-WATER SOLUTION
F. T-2, ETHANOL-NaOH SOLUTION

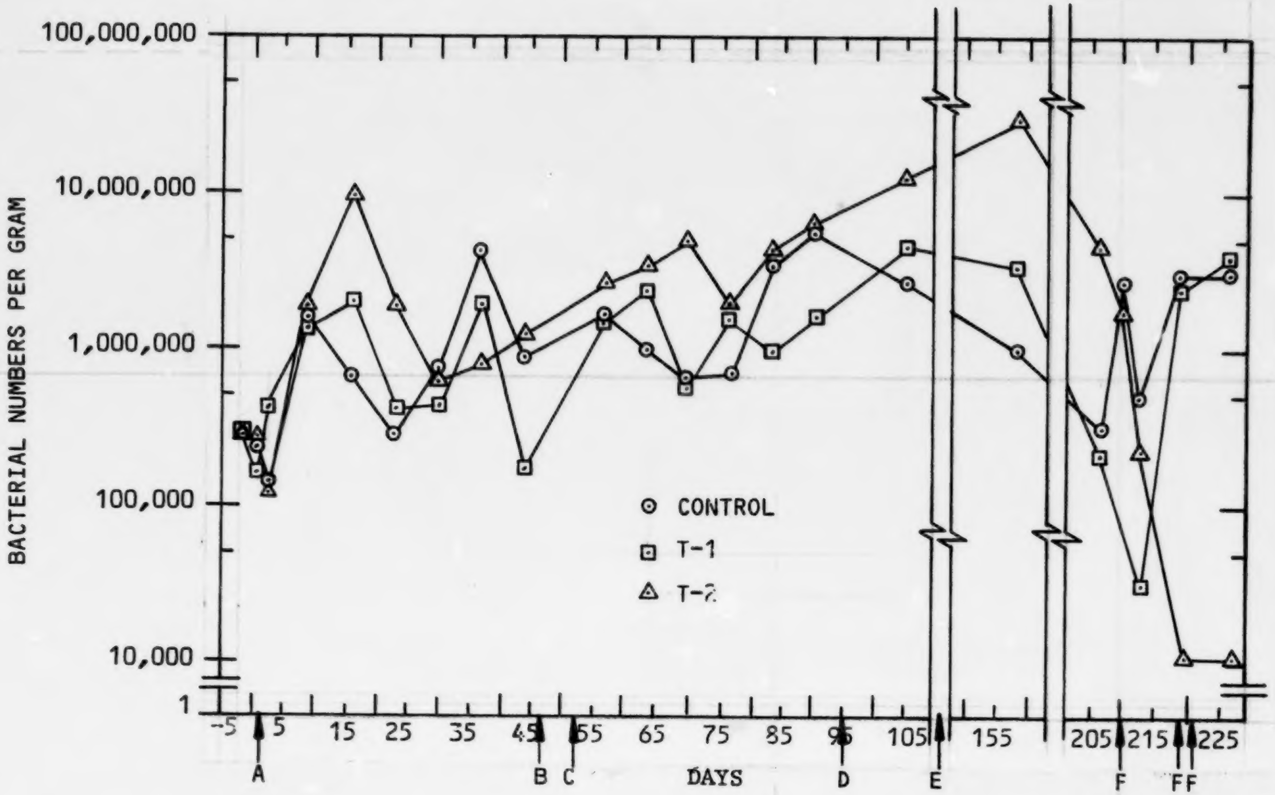


Figure C-3. Middle level sandy soil bacterial populations - Ethion spill.

EPA-287 (Cin.)
(4-76)

A. T-1 AND T-2, NUTRIENT BROTH, T-2 PLOWED
B. T-1 AND T-2, LIMED, T-2 PLOWED
C. T-1 AND T-2, LIMED AND NUTRIENT BROTH
D. T-1 AND T-2, NUTRIENT BROTH AND TWEEN 80
E. T-1 AND T-2, ETHANOL-WATER SOLUTION
F. T-2, ETHANOL-NaOH SOLUTION

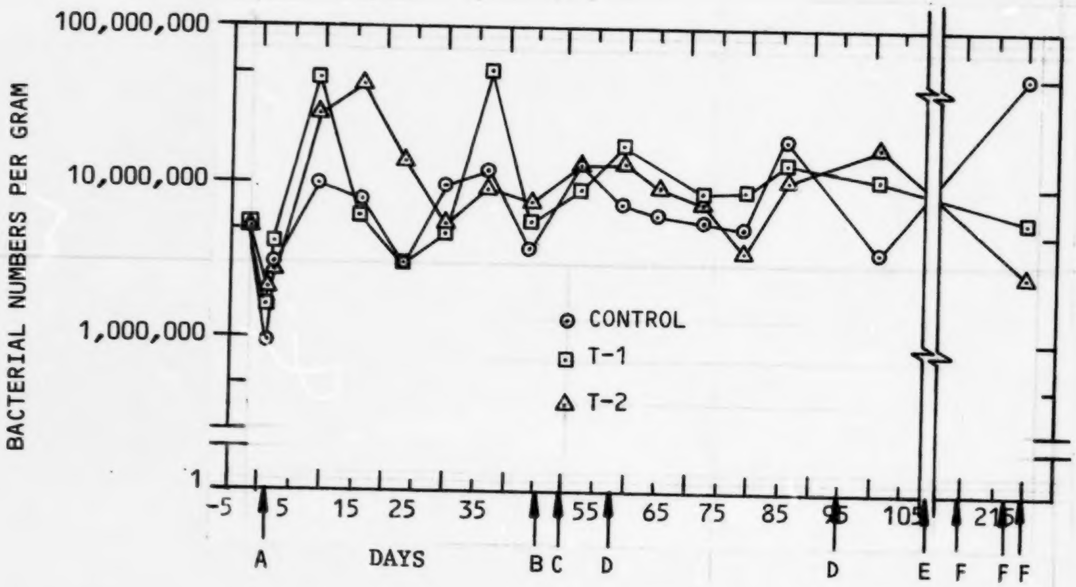


Figure C-4. Lower level sandy soil bacterial population - Ethion spill.

EPA-287 (Cin.)
(4-76)

A. T-1 AND T-2, NUTRIENT BROTH, T-2 PLOWED
B. T-1 AND T-2, LIMED, T-2 PLOWED
C. T-1 AND T-2, LIMED AND NUTRIENT BROTH
D. T-1 AND T-2, NUTRIENT BROTH AND TWEEN 80
E. T-1 AND T-2, ETHANOL-WATER SOLUTION
F. T-2, ETHANOL-NaOH SOLUTION

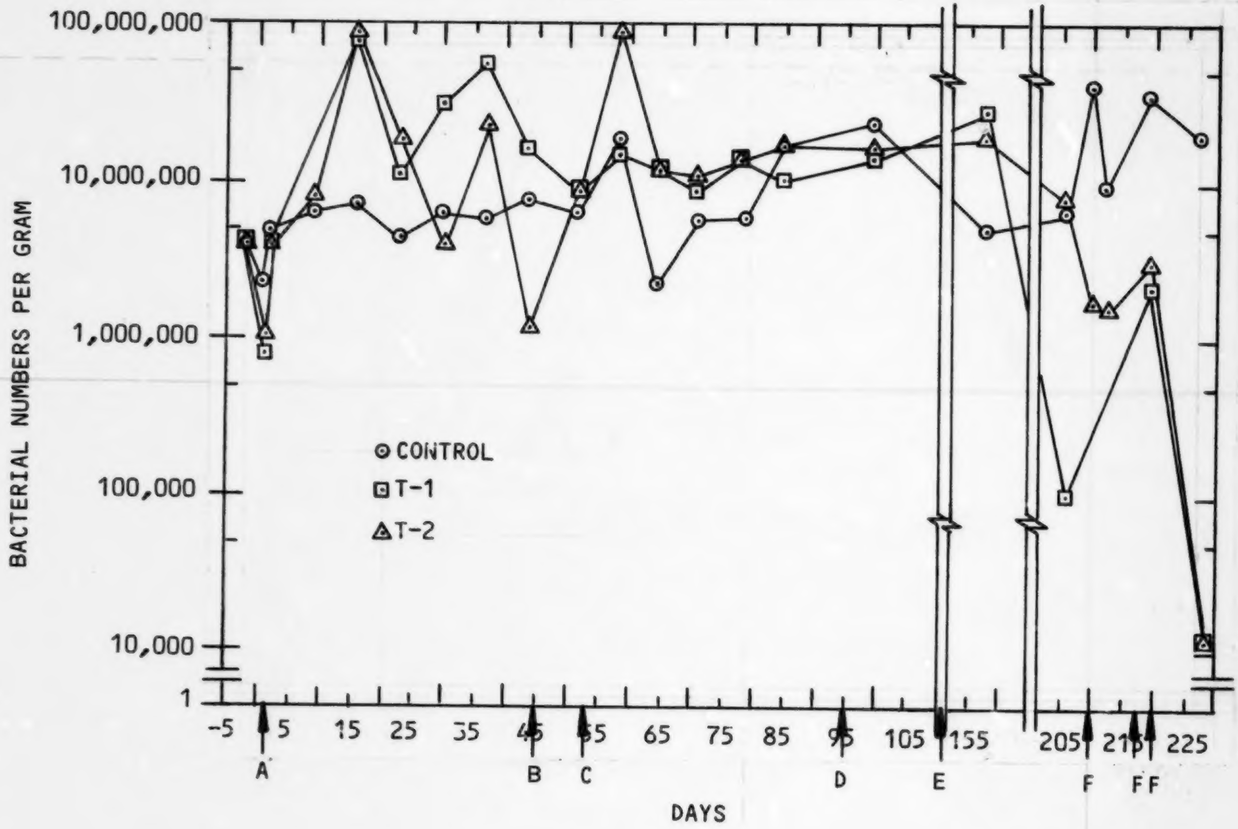


Figure C-5. Middle level clay soil bacterial populations - Ethion spill.

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 283)
TYPING GUIDE SHEET

A. T-1 AND T-2, NUTRIENT BROTH, T-2 PLOWED
B. T-1 AND T-2, LIMED, T-2 PLOWED
C. T-1 AND T-2, LIMED AND NUTRIENT BROTH
D. T-1 AND T-2, NUTRIENT BROTH AND TWEEN 80
E. T-1 AND T-2, ETHANOL- WATER SOLUTION
F. T-2, ETHANOL-NaOH SOLUTION

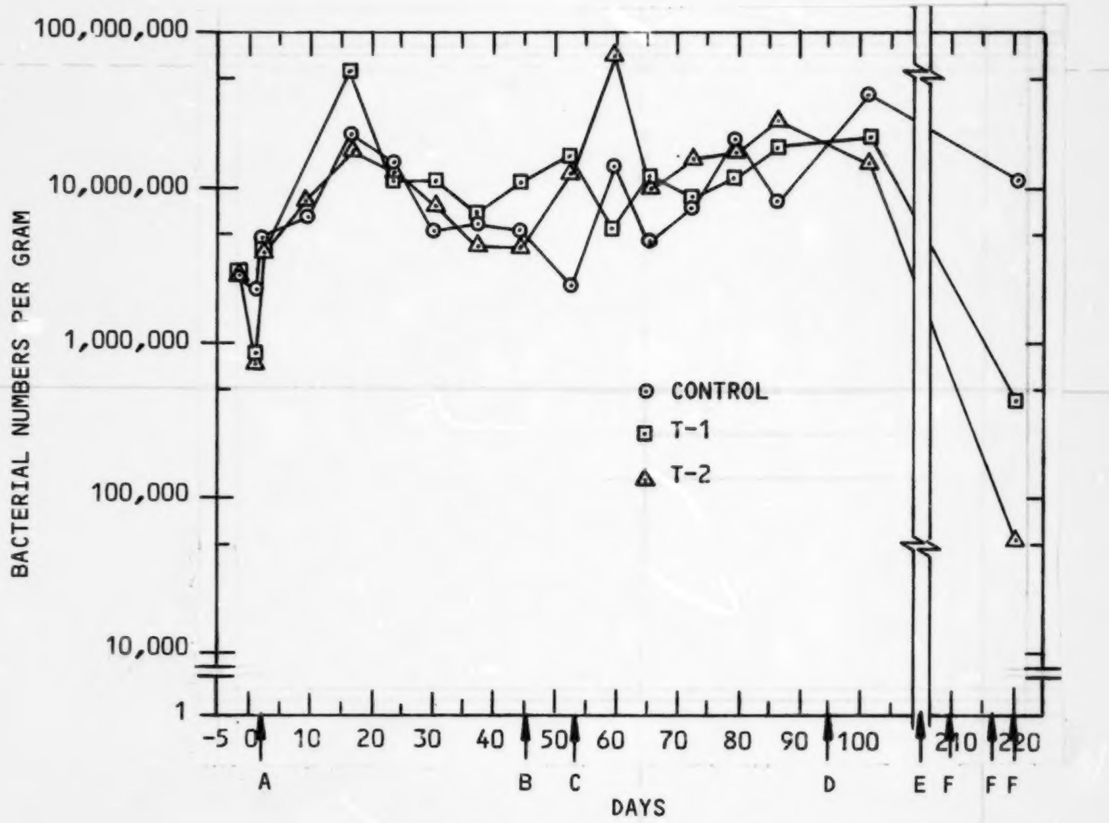


Figure C-6. Lower level clay soil bacterial populations - Ethion spill.

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 287)
TYPING GUIDE SHEET

A. T-1 AND T-2, NUTRIENT BROTH, T-2 PLOWED
B. T-1 AND T-2, LIMED, T-2 PLOWED
C. T-1 AND T-2, LIMED AND NUTRIENT BROTH
D. T-1 AND T-2, NUTRIENT BROTH AND TWEEN 80
E. T-1 AND T-2, ETHANOL-WATER SOLUTION
F. T-2, ETHANOL-NaOH SOLUTION

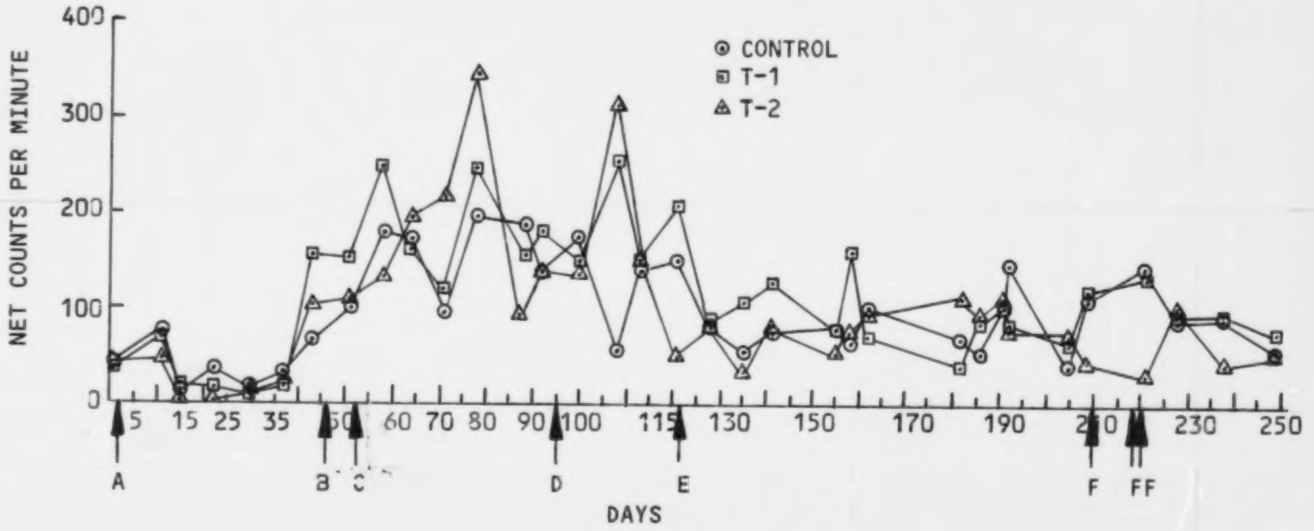


Figure C-7. Carbon-14 levels in upper level organic soil - Ethion spill.

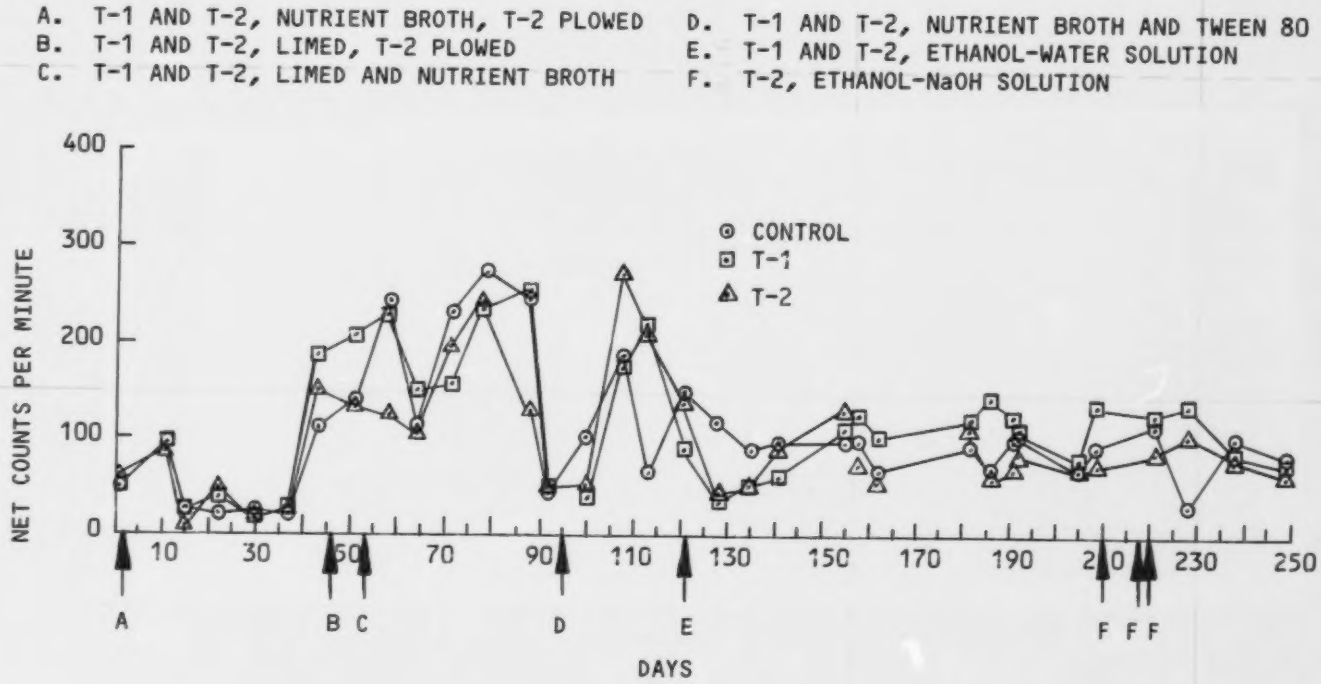


Figure C-8. Carbon-14 level in upper level - sandy soil - Ethion spill.

A. T-1 AND T-2, NUTRIENT BROTH, T-2 PLOWED
B. T-1 AND T-2, LIMED, T-2 PLOWED
C. T-1 AND T-2, LIMED AND NUTRIENT BROTH
D. T-1 AND T-2, NUTRIENT BROTH AND TWEEN 80
E. T-1 AND T-2, ETHANOL-WATER SOLUTION
F. T-2, ETHANOL-NaOH SOLUTION

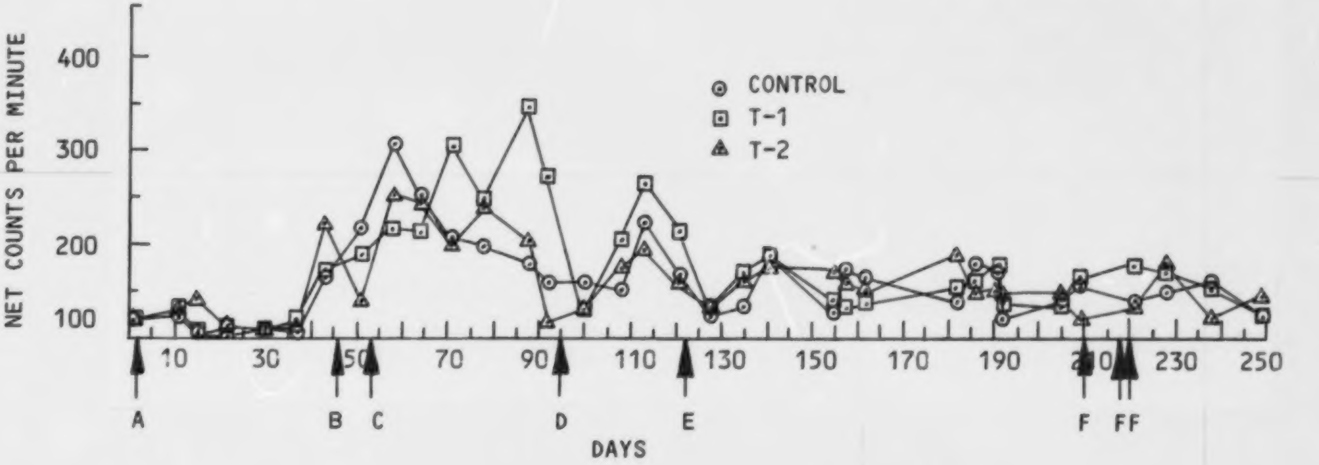


Figure C-9. Carbon-14 level in upper level - clay soils - Ethion spill.

APPENDIX D

FORMALDEHYDE DATA

This Appendix contains additional supplemental data obtained on land restoration techniques for the formaldehyde spill. The following data are included in this Appendix.

- background soil analyses
- pH of soils as a function of core depth and time
- percent moisture of soils as a function of core depth and time
- formaldehyde levels in the middle and lower soil layers
- microbial levels in the middle and lower soil layers
- radiometric data in the upper soil layers

EPA Form 2350-8 (4-80)
(PREVIOUSLY OH EPA FORM 387)
TYPING GUIDE SHEET

TABLE D-1. BACKGROUND ANALYSES OF SOILS - FORMALDEHYDE SPILL

Property Meaasure	Depth (cm)	High Organic Soil	Sandy-Loam	Clay Soil
pH	0-5	7.1	5.7	5.4
	5-10	6.9	6.0	6.5
	10-30	6.8	5.9	6.2
% Moisture	0-5	21.5	9.6	11.7
	5-10	15.4	1.5	13.8
	10-30	16.2	16.6	14.2
% Organic Matter	0-5	11.8	6.6	6.0
	5-10	6.0	6.7	5.5
	10-30	5.8	7.0	5.3
Nitrate N (ppm)	0-5	7.0	5	7.5
	5-10	7.0	4.5	8.0
	10-30	3.0	6.0	8.0
Organic Phosphorus (ppm)	0-5	1.0	0.1	12
	5-10	7.5	0.1	7.5
	10-30	3.0	10.5	0.1
Total Phosphorus (ppm)	0-5	60	13	19
Potassium (ppm)	0-5	55	139	45
Calcium (ppm)	0-5	624	1200	708
Magnesium (ppm)	0-5	57	120	107

TABLE D-2. pH OF ORGANIC SOIL CORE SEGMENTS - FORMALDEHYDE SPILL

Depth (cm)	Days																		
	0	1	2	4	5	7	9	11	15	18	22	25	28	32	36	42	49	56	66
Control																			
0-5	7.1	8.0	9.5	8.0	6.3	5.9	6.0	5.6	5.7	6.1	5.9	6.2	6.2	5.7	6.2	5.7	6.2	5.2	5.6
5-10	6.9	7.9	8.7	7.7	5.6	5.7	5.3	5.2	5.4	5.5	5.4	6.1	5.8	5.7	5.5	5.9	6.1	5.1	5.5
10-30	6.8	7.7	8.5	6.9	5.8	5.7	5.3	5.0	5.1	5.6	5.4	5.5	5.8	5.4	5.8	4.7	6.0	4.7	5.3
T-1	*																		
0-5	*	7.8	7.5	7.8	6.0	6.0	5.9	4.4	5.5	5.4	5.5	5.9	5.4	5.4	5.4	5.6	5.4	5.9	6.3
5-10	*	7.3	7.3	6.7	5.7	5.8	5.7	5.1	5.5	5.1	4.8	4.4	5.8	4.9	5.3	5.7	5.0	5.3	5.2
10-30	*	7.1	7.1	6.4	5.7	5.3	5.8	4.7	5.2	5.5	5.8	5.4	5.3	4.7	4.7	4.6	4.8	4.3	4.4
T-2																			
0-5	*	8.9	8.9	7.6	6.0	5.9	5.8	5.8	5.5	5.7	5.8	5.7	6.4	5.7	5.6	5.8	6.5	6.1	6.4
5-10	*	7.3	7.3	7.9	5.6	5.6	5.5	5.3	4.9	5.7	5.4	5.6	5.0	5.3	5.0	5.6	5.7	5.3	5.6
10-30	*	7.9	7.9	7.9	5.7	5.7	5.8	5.3	5.2	5.5	5.6	5.7	5.2	5.2	5.5	5.4	5.4	4.7	5.5

* Assumed to be similar to control

Lime added on day 52 and 64 to T-1 and T-2.

TABLE D-3. pH OF SANDY SOIL CORE SEGMENTS - FORMALDEHYDE SPILL

Depth (cm)	Days 0	1	2	4	5	7	9	11	15	18	22	25	28	32	36	42	49	56	66
Control																			
0-2	6.0	7.3	6.7	7.8	4.8	4.8	5.1	4.5	4.5	4.8	4.7	4.9	4.7	4.7	4.7	4.4	4.8	4.0	4.9
2-4	5.9	6.3	6.5	7.0	5.0	5.6	5.1	5.0	4.6	5.9	4.7	4.9	5.0	4.6	4.8	4.6	4.8	4.1	4.3
4-12	7.1	6.5	6.3	7.3	5.5	6.2	5.6	5.0	5.8	5.4	5.4	5.9	5.5	4.5	5.5	6.1	5.4	5.3	5.4
T-1																			
0-2	*	7.0	7.1	6.6	4.9	4.7	5.0	4.7	4.9	5.5	4.7	4.9	5.2	4.6	5.3	4.8	5.5	5.3	6.0
2-4	*	6.8	7.3	6.2	4.9	4.8	5.4	5.0	5.1	5.1	4.8	4.9	5.3	5.1	5.8	4.7	5.3	4.8	5.6
4-12	*	7.3	7.0	6.7	5.9	5.8	5.8	5.6	5.8	5.6	5.7	5.8	5.8	4.8	6.2	4.9	5.4	5.1	5.2
T-2													4.7						
0-2	*	7.6	7.9	6.8	5.1	4.5	4.9	4.8	4.7	4.6	4.5	5.0	4.7	4.3	4.7	4.3	4.6	5.4	6.0
2-4	*	7.3	7.6	6.6	5.2	5.2	5.0	4.5	4.8	4.6	4.8	5.0	5.0	4.3	5.8	4.5	4.4	4.8	5.8
4-12	*	7.3	7.3	7.1	5.9	5.1	5.9	4.8	5.3	5.2	5.5	5.6	5.1	4.3	4.9	5.5	5.2	5.4	5.7

* Assumed to be similar to control

Lime added on day 52 and 64 to T-1 and T-2.

TABLE D-4. pH OF CLAY SOIL CORE SEGMENTS - FORMALDEHYDE SPILL

Depth (cm)	Days																		
	0	1	2	4	5	7	9	11	15	18	22	25	28	32	36	42	49	56	66
Control																			
0.5	5.4	6.8	6.7	5.3	4.8	5.2	4.7	4.4	4.6	4.8	5.6	5.0	4.7	4.4	4.5	4.4	4.6	4.2	4.1
5-10	6.5	6.8	6.6	5.5	5.1	5.5	5.3	5.0	4.7	5.3	4.9	5.9	4.9	4.8	5.8	5.0	5.4	5.0	5.0
10-30	6.2.	6.7	6.2	5.2	5.3	5.8	5.3	4.7	5.0	6.0	4.9	5.2	6.1	5.3	4.2	6.0	5.2	5.4	4.6
T-1																			
0.5	*	6.2	7.3	6.7	4.9	4.9	4.8	4.7	4.3	4.4	4.8	4.9	4.7	4.6	4.5	4.5	4.6	5.5	5.5
5-10	*	5.8	7.2	5.5	4.7	5.7	5.3	5.0	4.6	5.3	5.3	5.0	5.1	4.9	5.3	4.6	5.3	4.8	4.7
10-30	*	5.8	7.2	6.1	5.2	5.7	5.3	5.0	4.8	5.7	5.4	5.1	5.7	4.6	5.2	4.7	6.0	5.2	5.3
T-2																			
0-5	*	6.5	6.8	5.9	4.8	4.9	4.8	4.6	4.5	4.7	4.7	4.9	4.7	4.9	5.3	5.1	5.3	6.1	5.1
5-10	*	6.5	6.9	5.4	5.7	5.4	5.0	4.8	4.8	4.9	4.8	4.8	4.8	5.0	4.6	6.1	5.4	4.9	5.6
10-30	*	6.0	7.1	6.3	5.3	5.6	6.0	5.4	4.8	5.4	5.4	5.4	4.9	4.8	5.1	6.0	5.4	5.9	5.8

* Assumed to be similar to control

Lime added on day 52 and 64 to T-1 and T-2

TABLE D-5. PERCENT ORGANIC SOIL MOISTURE CONTENT - FORMALDEHYDE SPILL

Depth (cm)	Days 0	1	2	4	5	7	- 9	11	15	18	22	25	28	32	36	42	49	56	66
Control																			
0-5	21.5	23.5	30.1	26.2	25.8	-	26.1	23.3	22.5	18.6	24.7	24.8	22.5	-	29	28.9	24.6	28.8	27.4
5-10	15.4	19.1	20.7	19.1	18.7	-	24.6	19.7	21.8	21.6	21.4	21.5	18.3	-	28.2	20.5	22.1	20.8	23.1
10-30	16.2	16.1	13.6	16.3	-	-	20.3	18.1	21.3	18.5	20.2	18.6	16.3	-	17.9	19.5	20.7	19.4	22.8
T-1																			
0-5	*	22.7	24.6	29.2	30.1	24.5	25.3	28.3	28.7	22.4	18.9	27.1	23.7	29.0	26.1	27.5	23.8	26.2	37.6
5-10	*	21.9	20.5	21.1	21.0	22.7	20	17.2	26.4	19.3	23.9	21.1	23.8	19.3	20.9	23.1	21.3	21.5	21.7
10-30	*	19.8	19.7	19.3	23.9	19.0	18	20.1	19.5	19.6	27.1	20.9	22	21.6	12.8	19.9	21.9	23.4	22.8
T-2																			
0-5	*	21.0	24.0	21.8	16.8	22.8	16.4	16	15.1	33.8	24.1	23.8	24.1	16.5	28	18.7	19.8	31.6	23.8
5-10	*	9.0	17.0	15.0	13.3	18.0	14.6	18.1	19.1	13.7	19.9	17.7	18.2	15	17.1	16.3	17.9	18.5	22.6
10-30	*	14.1	15.5	7.2	15.9	17.7	15.3	13.7	17.2	15.9	20.3	17.9	19.4	19.6	17.8	16.2	19.3	17.2	20.6

* Assumed to be similar to control
All chambers watered after sampling on day 18, 21 and 49

TABLE D-6. PERCENT SANDY-LOAM SOIL MOISTURE CONTENT - FORMALDEHYDE SPILL

Depth (cm)	Days 0	1	2	4	5	7	9	11	15	18	22	25	28	32	36	42	49	56	66
Control																			
0-5	9.6	17.3	18.4	14.4	16.4	-	15.9	11.7	20.7	8.9	14.6	13.7	13.3	19.2	-	12.2	13.9	36.1	19
5-10	1.5	12.3	5.7	17.4	15.8	-	17.8	14.4	6.7	8.3	20.1	15.4	11.0	16.5	13.2	13.9	15.0	15.4	19.3
10-30	16.6	12.5	13.4	14.5	17.9	-	23.7	11.8	16.6	11.3	15.6	19.1	10.9	18.3	11.9	14.3	18.2	19.3	25.2
T-1																			
0-5	*	21.6	21.0	21.6	18.3	20.8	21.0	21.6	-	15.3	19.0	19.8	22.2	19.3	19.3	17.8	20.8	22.8	22.9
5-10	*	15.6	21.2	22.8	19.5	13.5	14.8	21.9	20	17.0	19.7	19.9	19.2	26.9	23.0	18.8	21.6	21.9	21.5
10-30	*	23.7	22.4	25.7	21.9	21.5	21.8	22	20.3	20.3	24.8	22	19.4	21.4	24.9	20.7	23.5	26.5	-
T-2																			
0-5	*	14.6	11.7	18.2	4.3	15.3	16.6	12.5	9.3	11.7	17.8	15.6	13.3	11.7	4.6	8.2	12.2	15.9	20.1
5-10	*	15.5	5.9	11.4	36.6	14.8	14.4	17.9	11.3	12.3	18.7	17.2	17.0	16.6	19.4	9.5	17.7	18.7	23.4
10-30	*	12.5	13.4	21.1	15.1	17.2	18.9	17.7	16.7	11.5	20.7	19.5	20.2	17.2	11.5	20.3	21.0	22.6	26.1

* Assumed to be similar to control

All chambers watered after sampling on day 18, 21 and 49

TABLE D-7. PERCENT CLAY SOIL MOISTURE CONTENT - FORMALDEHYDE SPILL

Depth (cm)	Days																		
	0	1	2	4	5	7	9	11	15	18	22	25	28	32	36	42	49	56	66
Control																			
0-5	11.7	20.8	16.0	16.4	16.6	14.8	30.5	20	15.2	14.1	15.2	22.6	15.2	14.3	21.1	18.9	14.9	8.2	17.3
5-10	13.8	14.3	-	16.4	11.8	6.7	16	14.6	14.3	15.3	17.1	14.1	16.9	16.3	16.5	14.8	15.7	16.1	18.9
10-30	14.2	13.5	16.6	17.9	14.9	15.3	16.4	15.2	17.8	17.8	16.9	20.3	18.6	17.2	18.7	16.4	16.3	31.4	17
T-1																			
0-5	*	14.0	12.1	16.2	15.3	16.3	22.7	15.6	14.5	14.5	14.3	14.7	14.7	15.5	13.5	11.9	14.7	16.7	21.4
5-10	*	13.4	9.3	13.7	13.4	16.9	17.1	16.8	14.4	20.1	16.4	14.5	17.0	15.4	17.2	12.8	15.9	12.8	20.1
10-30	*	20	15.2	18.1	18.0	16.8	13.8	13.9	13.5	17.4	19.8	17.5	16.7	17	20.4	16.5	18.1	16.4	18.5
T-2																			
0-5	*	15.5	13.8	16.7	12.1	10.7	14.4	11.5	12.0	9.7	14.7	13.6	17.0	12.3	16.6	14.5	12.5	18.6	17.7
5-10	*	10.1	13.3	16.3	15.8	14.1	13.8	16.1	19.1	11.4	13.9	14.4	15.5	20.7	9.0	9.1	13.4	13.4	8.7
10-30	*	8.6	6.1	15.5	13.6	10.9	14.0	11.1	13.9	13.5	16.9	15.8	16.5	16	17.8	14.6	14.8	14.5	19.8

* Assumed to be similar to control

All chambers watered after sampling on day 18, 21 and 49

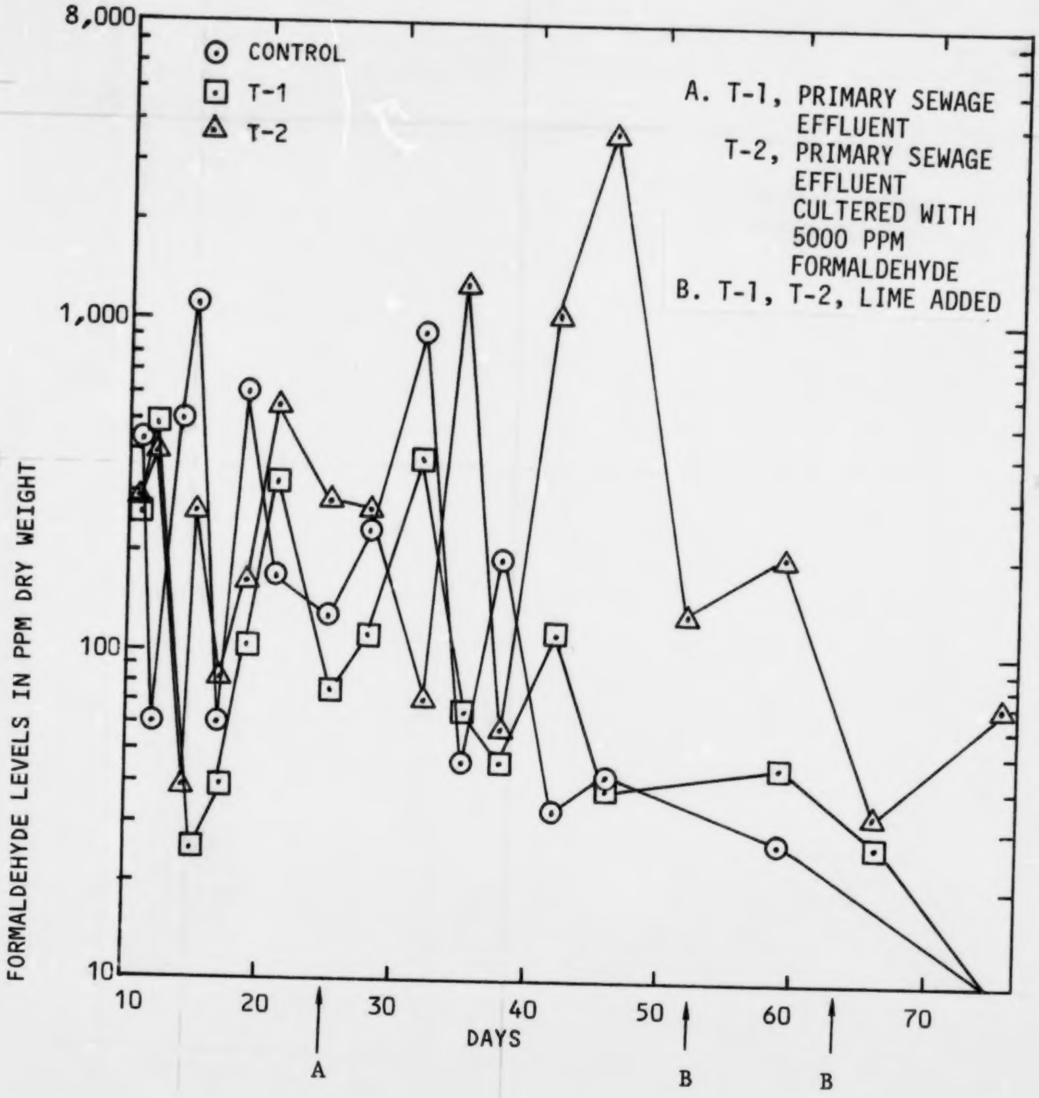


Figure D-1. Formaldehyde levels - middle soil layer (5-10 cm) - organic soil.

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 287)
TYPING GUIDE SHEET

BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD: BEGIN SECTIONS HERE

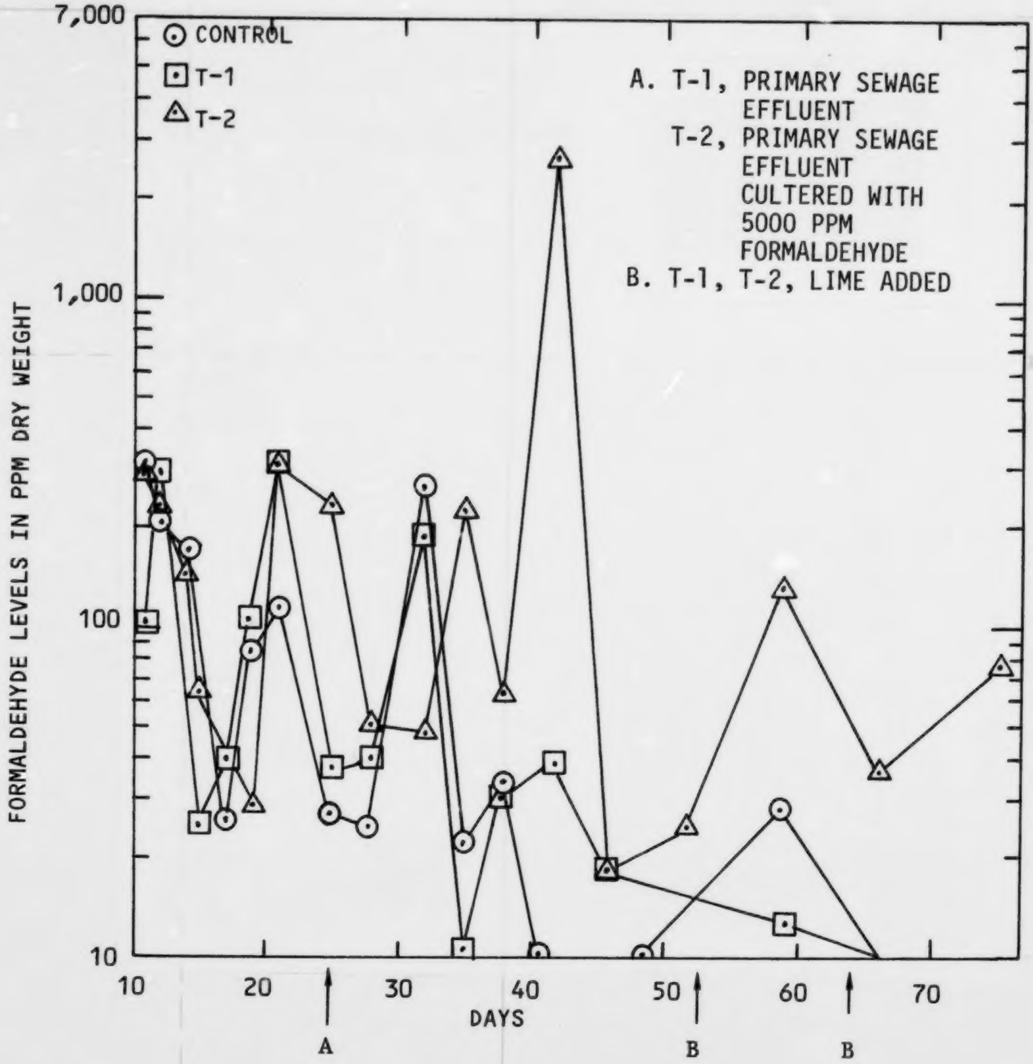


Figure D-2. Formaldehyde levels - lower soil layer (10-30 cm) - organic soil.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 287)
☆ U.S. GOVERNMENT PRINTING OFFICE: 1980-660-630
TYPING GUIDE SHEET

BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD: BEGIN SECTIONS HERE

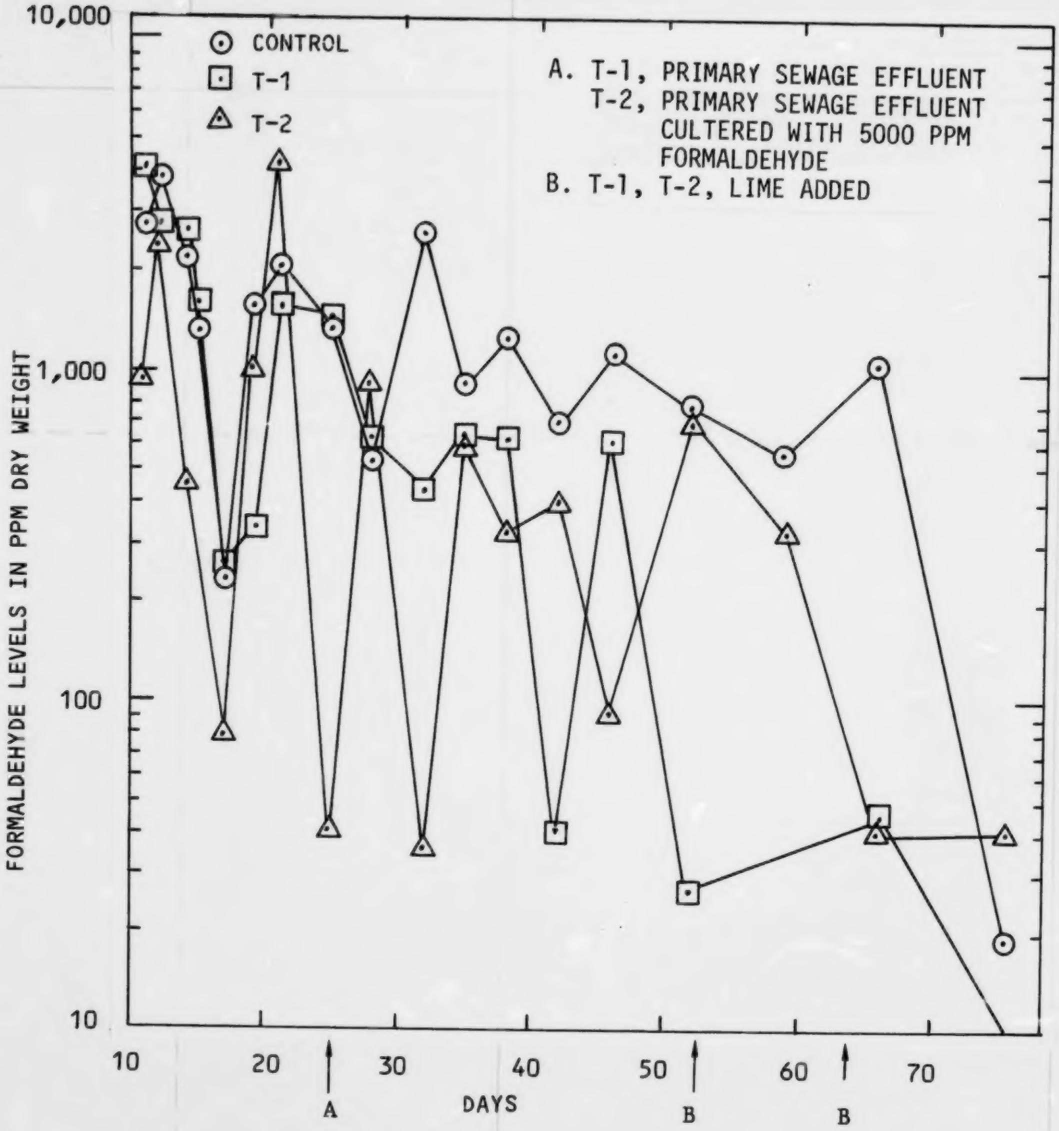


Figure D-3. Formaldehyde levels - middle soil layer (5-10 cm) - sandy soil.

BEGIN LAST LINE OF TEXT
3/8"
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS

PAGE NUMBER
EPA Form 2350-4 (4-80)
(PREVIOUSLY EIN EPA FORM 247)
U.S. GOVERNMENT PRINTING OFFICE
TYPING GUIDE SHEET

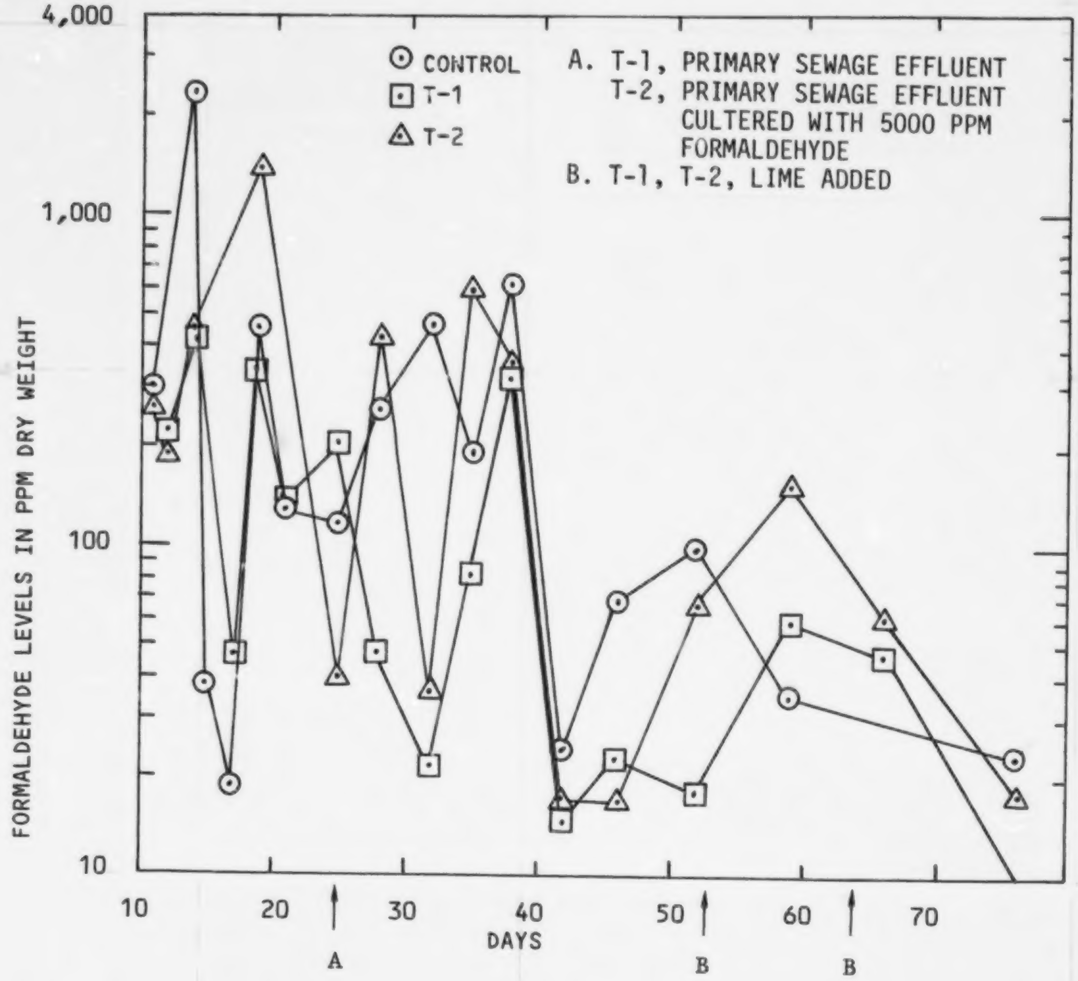


Figure D-4. Formaldehyde levels - lower soil layer (10-30 cm) - sandy soil.

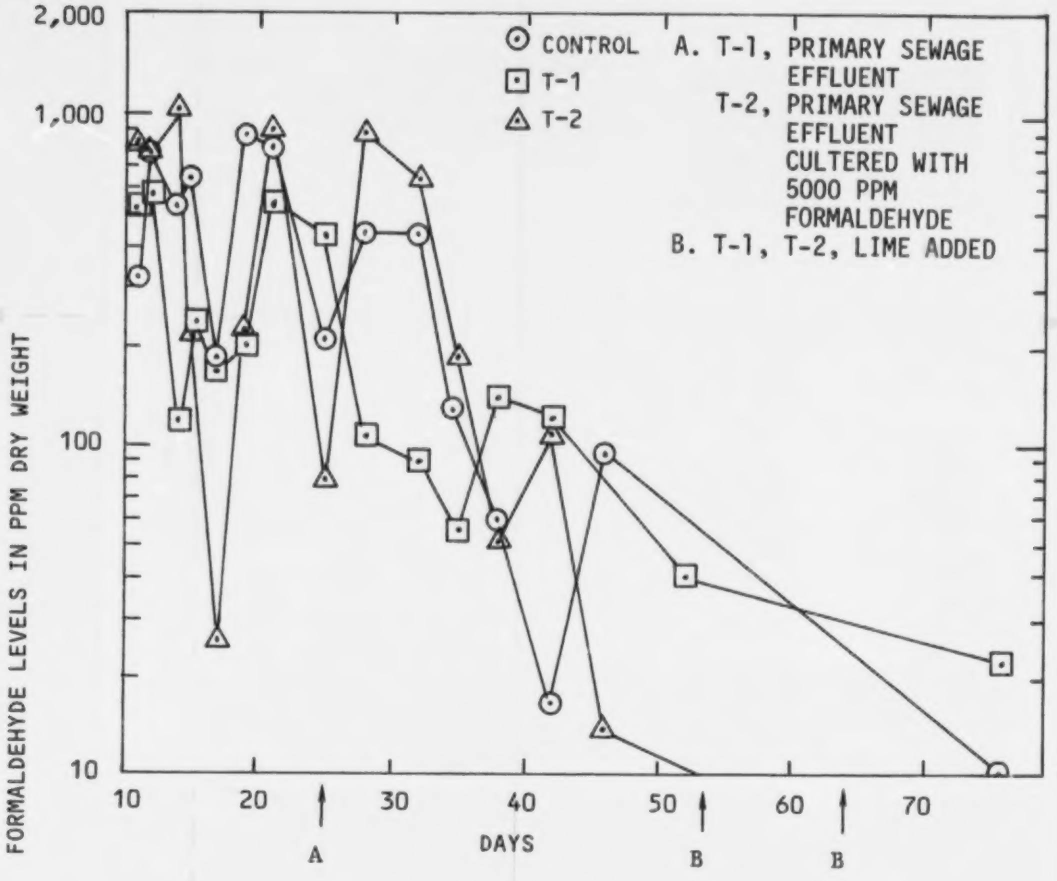


Figure D-5. Formaldehyde levels - middle soil layer (5-10 cm) - clay soil.

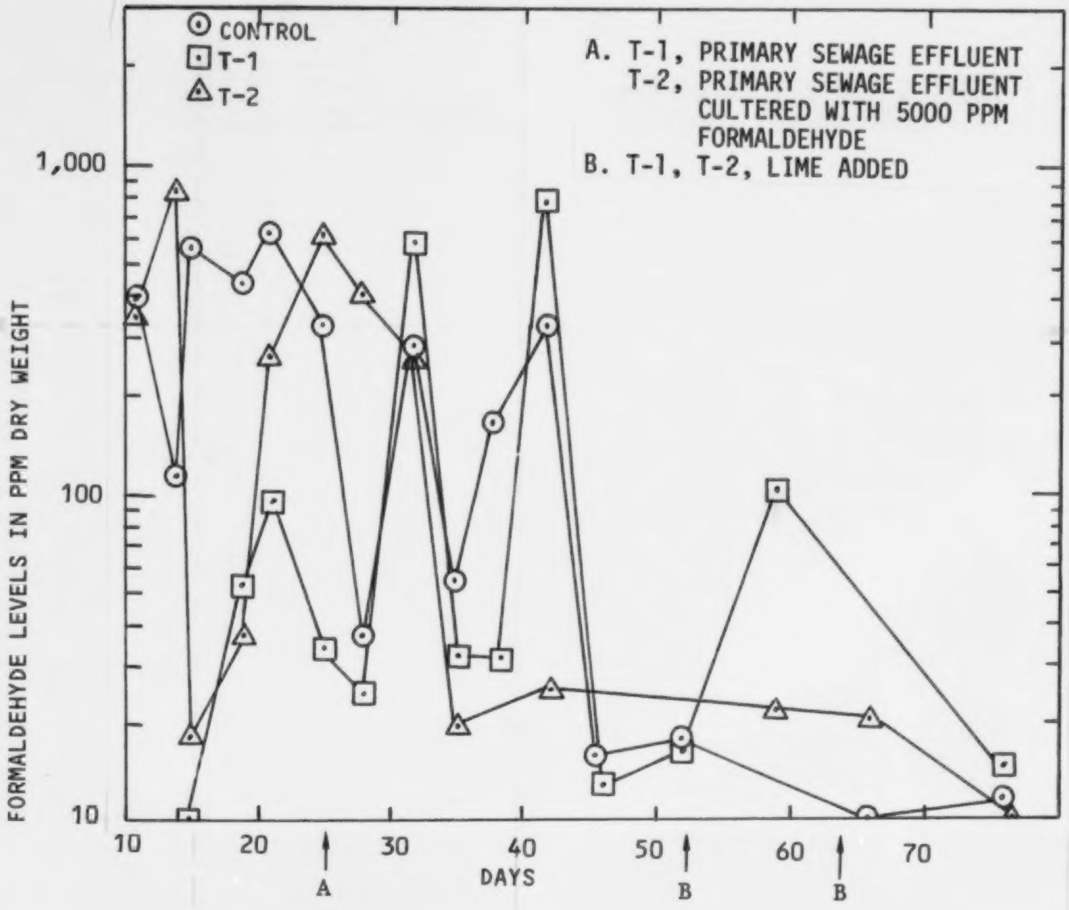


Figure D-6. Formaldehyde levels - lower soil layer (10-30 cm) - clay soil.

EPA Form 2350-6 (4-80)
(PREVIOUSLY 2IN- EPA FORM 337)
TYPING GUIDE SHEET

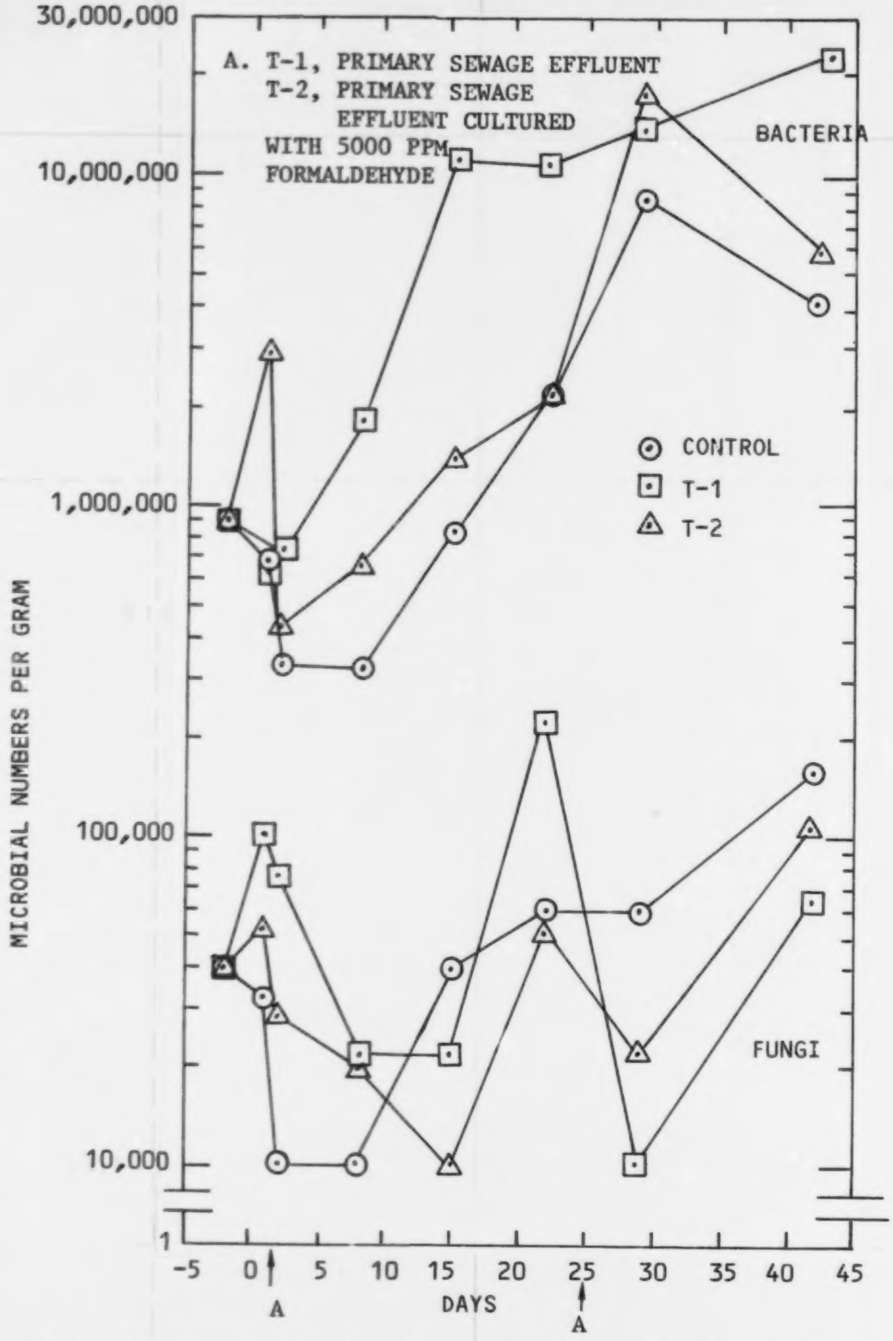


Figure D-7. Middle level organic soil microbial population - formaldehyde spill.

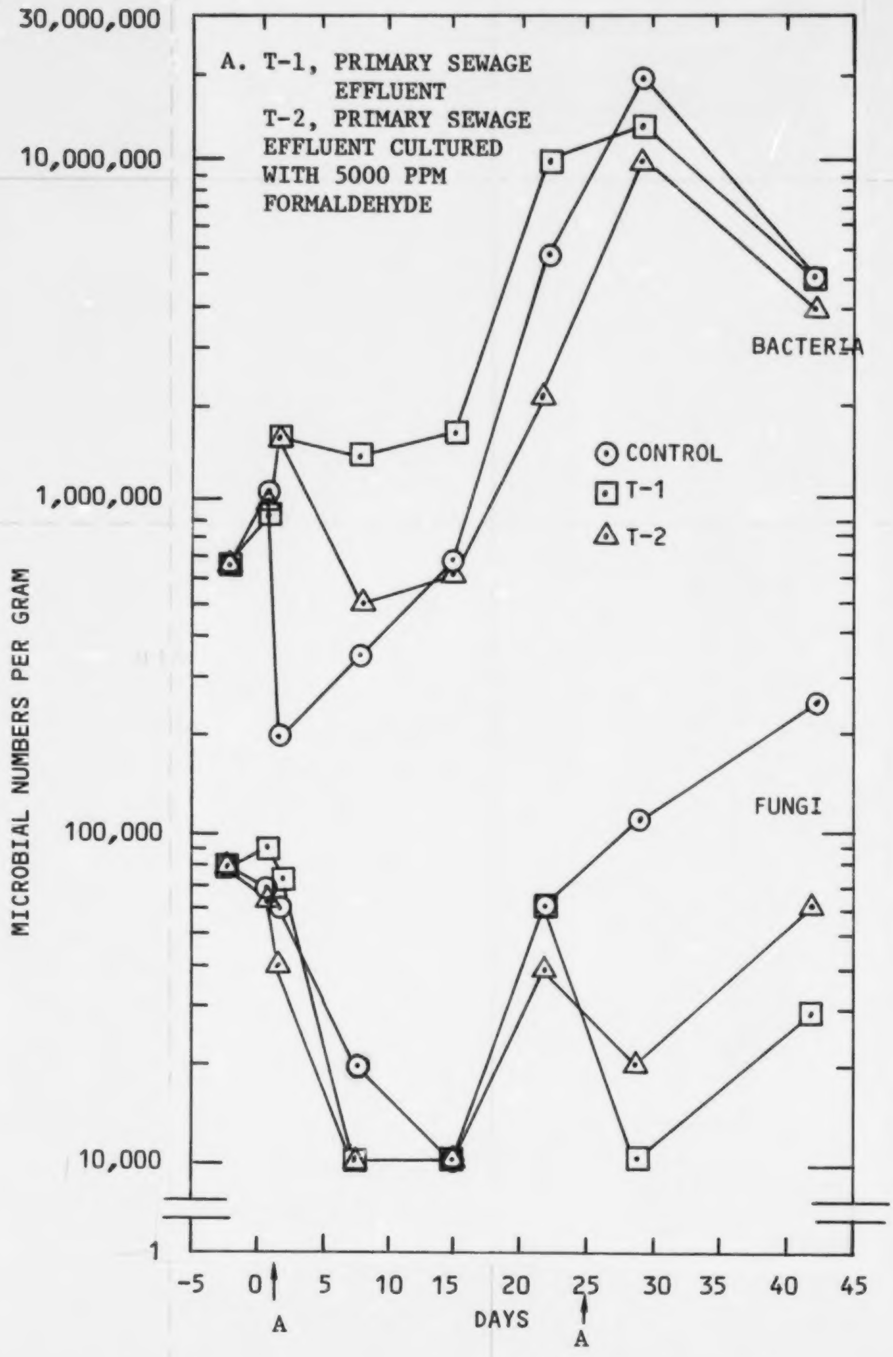


Figure D-8. Lower level organic soil microbial population - formaldehyde spill.

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 387)
TYPING GUIDE SHEET

BEGIN FIRST LINE OF TEXT HERE
CENTER OF
TOP OF IMAGE AREA
DROPPED HEAD: BEGIN SECTIONS HERE

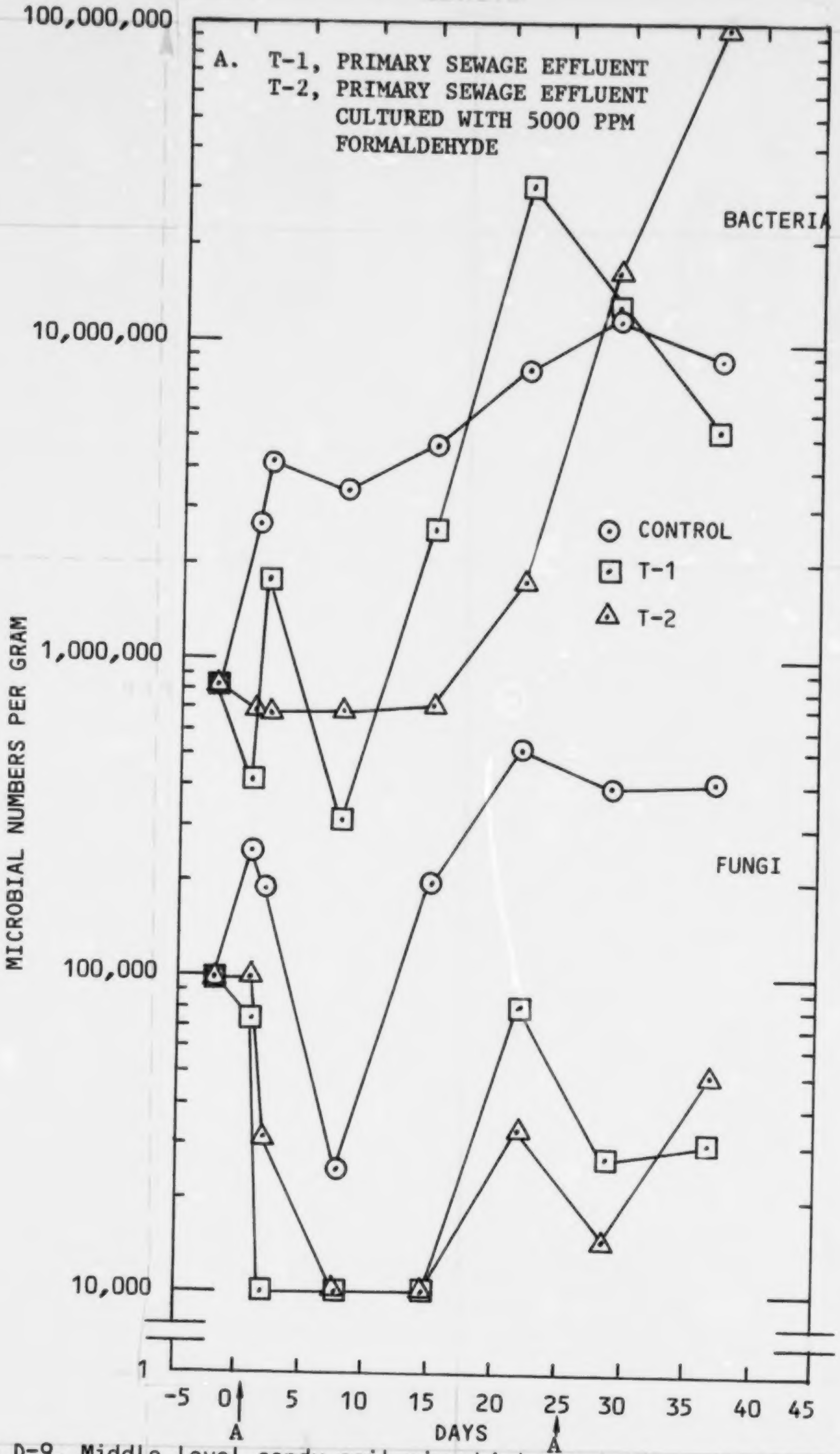


Figure D-9. Middle level sandy soil microbial population - formaldehyde spill.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA, OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
PAGE NUMBER
EPA Form 2350-4 (4-80)
(PREVIOUSLY EPA FORM 337)
U.S. GOVERNMENT PRINTING OFFICE: 1980-
TYPING GUIDE SHEET

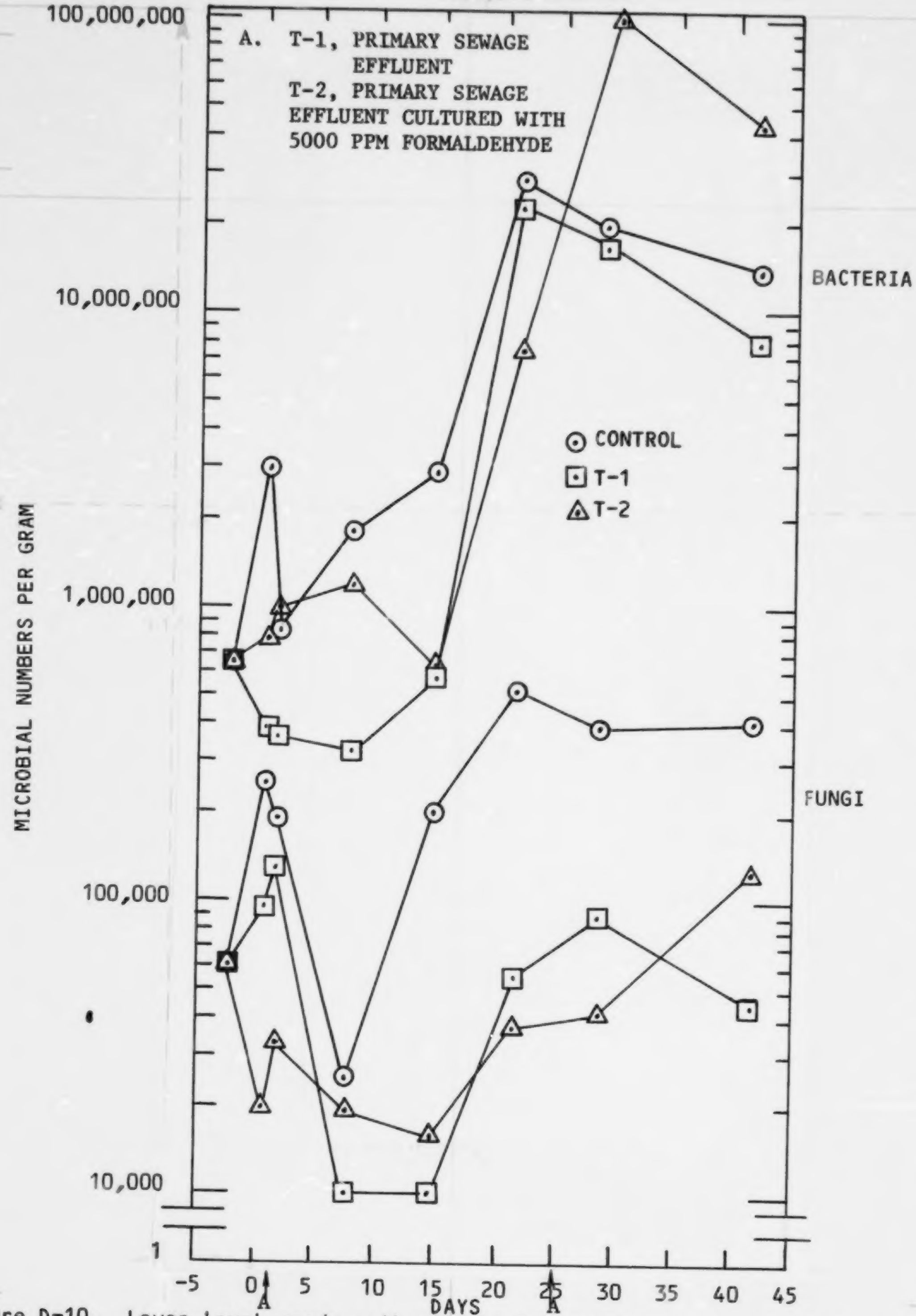


Figure D-10. Lower level sandy soil microbial population - formaldehyde spill.

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 287)
TYPING GUIDE SHEET

BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD: BEGIN SECTIONS HERE

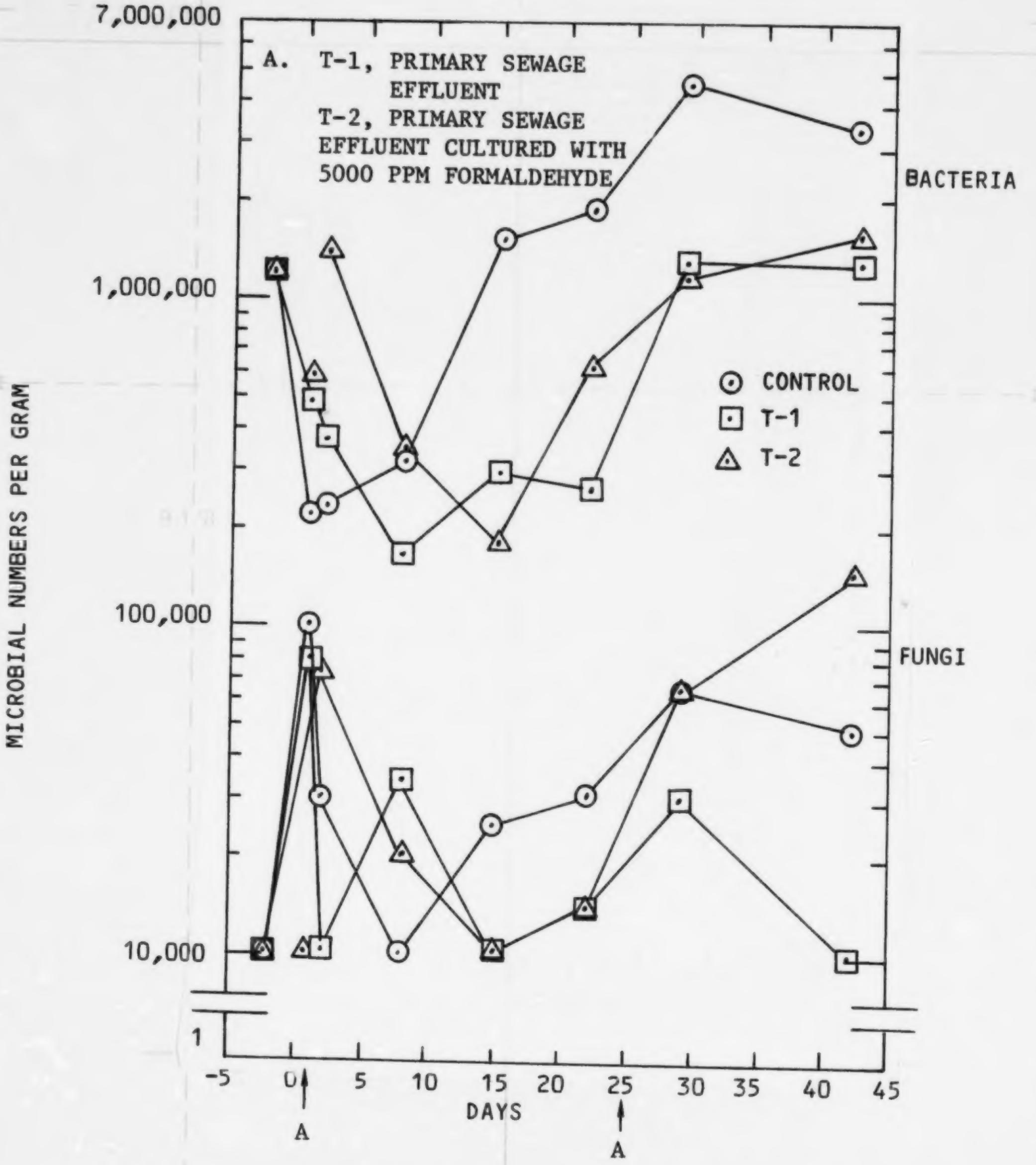


Figure D-11. Middle level clay soil microbial population - formaldehyde spill.

BEGIN LAST LINE OF TEXT
3/8"
BOTTOM OF IMAGE AREA: OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS

PAGE NUMBER
EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 287)
© U.S. GOVERNMENT PRINTING OFFICE 1980-660-839
TYPING GUIDE SHEET

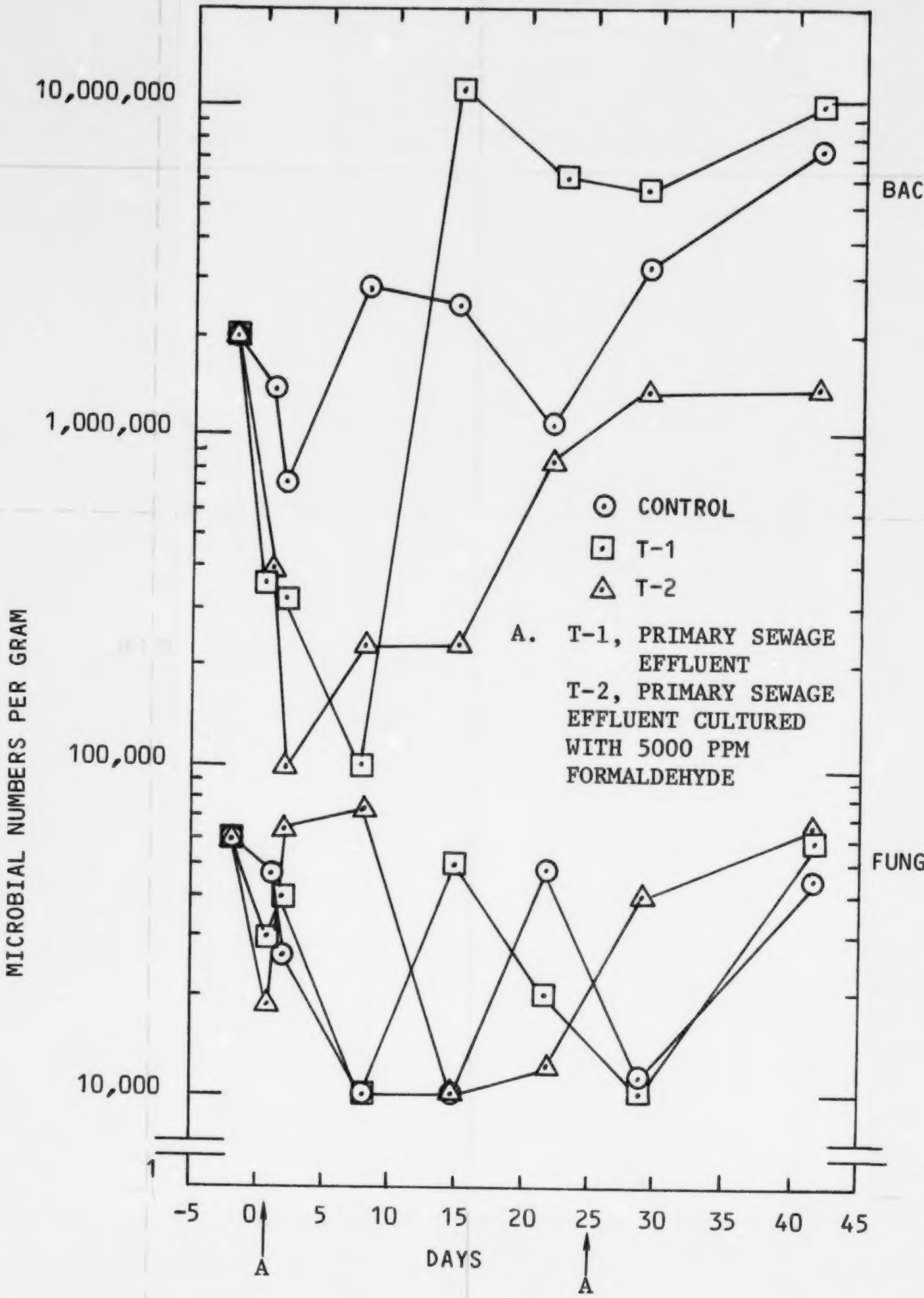


Figure D-12. Lower level clay soil microbial level population - formaldehyde spill.

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 227)
TYPING GUIDE SHEET

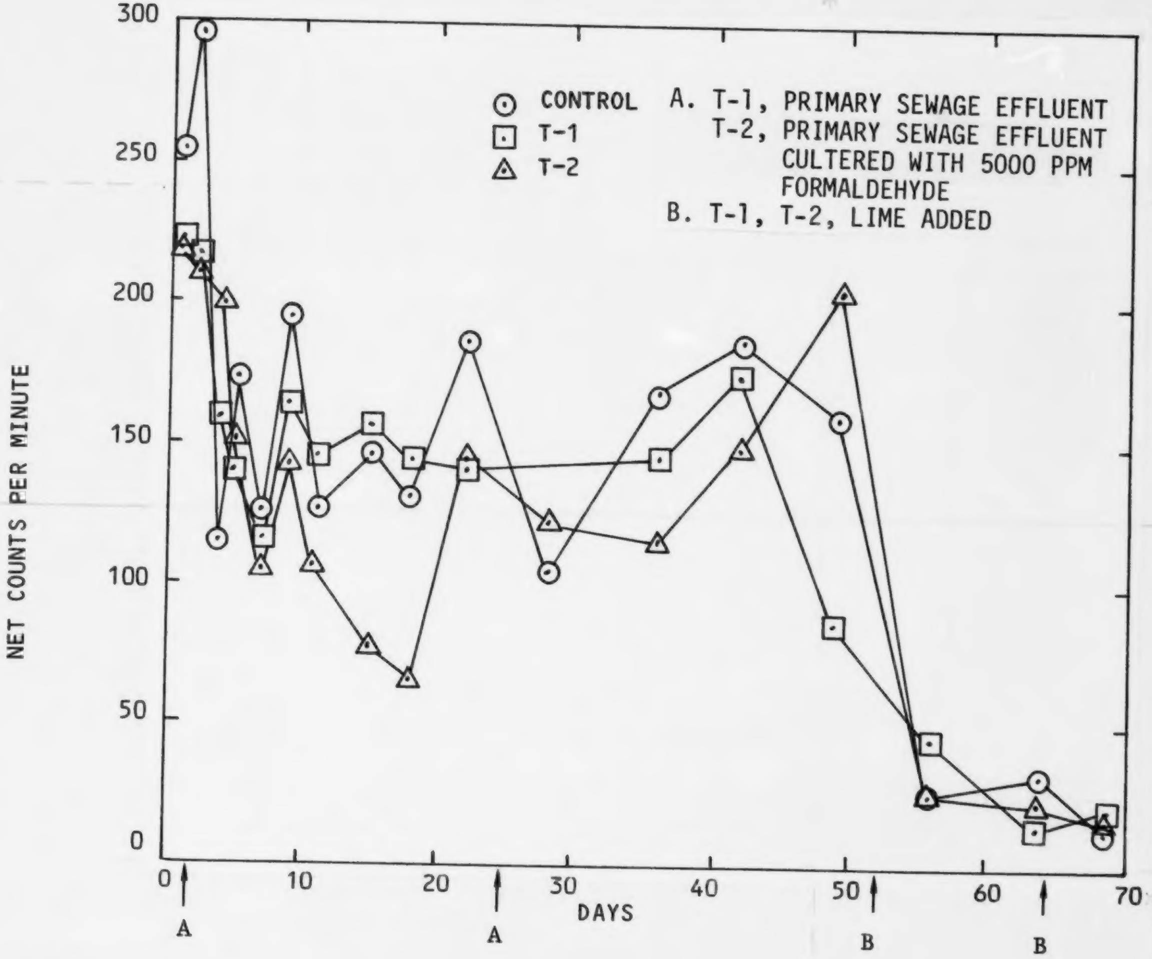


Figure D-13. Radiation counts in upper layer of organic soils - formaldehyde spill.

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 287)
U.S. GOVERNMENT PRINTING OFFICE 1980-
TYPING GUIDE SHEET

BEGIN FIRST LINE OF TEXT HERE
DROPPED HEAD; BEGIN SECTIONS HERE
CENTER OF PAGE
TOP OF IMAGE AREA

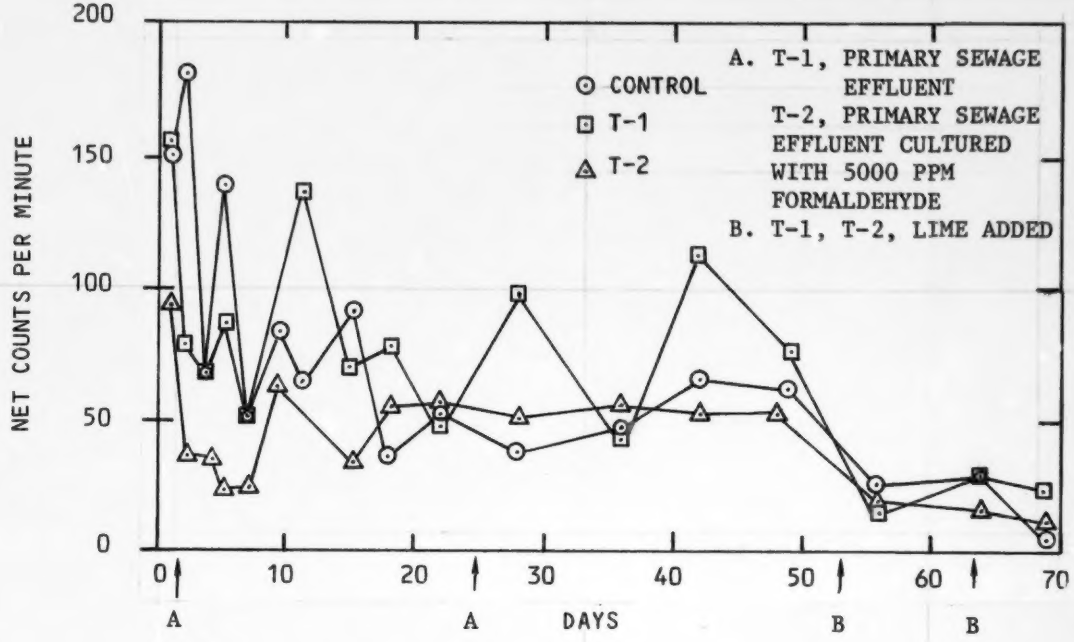


Figure D-14. Radiation counts in upper layer of sandy soils - formaldehyde spill.

BEGIN LAST LINE OF TEXT
3/8"
BOTTOM OF IMAGE AREA, OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
PAGE NUMBER

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN EPA FORM 267)
☆ U.S. GOVERNMENT PRINTING OFFICE 1980-680-639
TYPING GUIDE SHEET

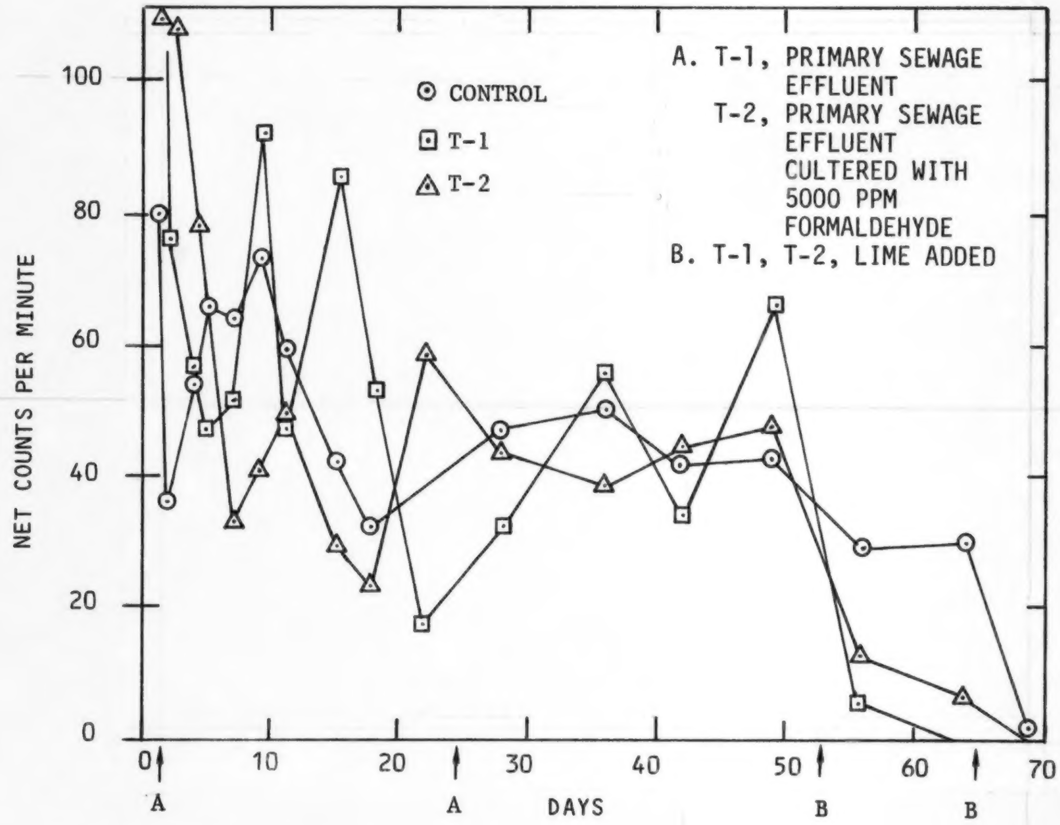


Figure D-15. Radiation counts in upper level of clay soils - formaldehyde spill.

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 287)
TYPING GUIDE SHEET

APPENDIX E

ANILINE DATA

This appendix contains additional supplemental data obtained on land restoration techniques for the aniline spill. The following data are included in this Appendix.

- background soil analyses
- pH of soil as a function of core depth and time
- percent moisture of soils as a function of core depth and time
- Aniline concentration - middle soil layers

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 257)
TYPING GUIDE SHEET

TABLE E-1. BACKGROUND ANALYSES OF SOILS - ANILINE SPILL

Property Measured	Depth (cm)	Organic Soil	Sandy-loam Soil	Clay Soil
pH	0-5	7.5	6.6	5.1
	5-10	6.2	6.4	5.8
	10-30	6.2	6.7	5.5
% Moisture	0-5	24.3	18.2	15.7
	5-10	22.4	19.1	26.0
	10-30	27.6	22.8	12.7
% Organic Matter	0-5	15.7	2.0	2.0
	5-10	5.9	2.9	0.9
	10-30	9.0	2.9	1.0
Nitrate N (ppm)	0-5	5	10	17
	5-10	17	7	6
	10-30	10	10	0
Total Phosphorus (ppm)	0-5	60	13	19
Potassium (ppm)	0-5	55	139	45
Calcium (ppm)	0-5	624	1200	708
Magnesium (ppm)	0-5	57	120	107

TABLE E-2. pH OF ORGANIC SOILS - ANILINE SPILL

Depth (cm)	Pre-Aniline Sample -2	Days 1	2	5	7	14	15	17	34	37	43	50	57
Control													
0-5	7.5	7.0	6.55	4.7	7.45	7.5	7.4	7.1	7.5	7.3	7.15	7.15	7.3
5-10	6.15	6.3	6.25	-	6.5	-	-	-	6.7	-	-	-	-
10-30	6.2	5.15	6.25	-	5.8	-	-	-	-	-	-	-	-
T-1													
0-5	*	7.15	6.55	5.7	7.15	7.5	7.45	6.7	7.8	7.25	7.1	7.1	7.3
5-10	*	5.4	5.8	-	5.7	-	-	-	6.0	-	-	-	-
10-30	*	4.8	5.6	-	5.4	-	-	-	-	-	-	-	-
T-2													
0-5	*	7.2	6.05	7.2	7.1	7.1	6.1	6.6	6.4	6.8	6.4	6.3	6.1
5-10	*	5.0	4.8	-	5.55	-	-	-	6.2	-	-	-	-
10-30	*	5.4	5.25	-	5.7	-	-	-	-	-	-	-	-

*assumed same as control

(continued)

TABLE E-2. (continued)

Depth (cm)	Days 71	77	84	91	100	105	113	124	133	141	152	159	166
Control													
0-5	7.2	7.2	7.4	7.3	7.35	7.5	7.1	7.5	6.2	7.25	7.35	7.4	7.25
5-10	7.0	6.75	6.8	6.35	6.8	6.2	6.9	7.5	7.3	6.3	7.25	6.0	7.3
10-30	-	-	-	-	-	-	-	-	-	-	-	-	-
T-1													
0-5	7.3	7.1	8.4	7.6	7.2	7.5	7.4	7.6	7.3	7.4	7.3	7.4	7.4
5-10	7.0	5.9	6.8	6.9	6.9	6.9	6.4	7.6	6.6	6.6	6.2	6.3	7.3
10-30	-	-	-	-	-	-	-	-	-	-	-	-	-
T-2													
0-5	6.2	6.4	6.9	5.1	6.8	6.5	6.3	6.45	6.6	6.8	6.6	7.3	6.6
5-10	6.6	6.8	7.0	6.0	5.8	6.8	7.0	7.7	6.8	6.95	7.4	7.1	7.35
10-30	-	-	-	-	-	-	-	-	-	-	-	-	-

(continued)

TABLE E-2. (continued)

Depth (cm)	Days 174	181
Control		
0-5	7.2	7.3
5-10	7.0	5.5
10-30	-	-
T-1		
0-5	7.3	7.1
5-10	6.6	5.3
T-2		
0-5	7.0	7.1
5-10	7.2	7.4
10-30	-	-

TABLE E-3. pH OF SANDY SOILS - ANILINE SPILL

Depth (cm)	Pre-Aniline Sample	Days											
	-2	1	2	5	7	14	15	17	34	37	43	50	57
Control													
0-5	6.1	7.05	6.95	4.0	7.1	7.2	7.2	6.9	7.0	7.1	6.9	6.9	7.1
5-10	5.8	6.55	6.5	-	6.0	-	-	-	6.9	-	-	-	-
10-30	5.5	6.25	5.55	-	5.85	-	-	-	-	-	-	-	-
T-1													
0-5	*	6.45	6.5	6.3	6.6	6.7	6.8	6.4	6.8	6.65	6.5	6.3	6.7
5-10	*	5.8	6.1	-	6.3	-	-	-	6.7	-	-	-	-
10-30	*	5.6	5.85	-	6.15	-	-	-	-	-	-	-	-
T-2													
0-5	*	7.1	7.05	7.5	6.3	6.6	5.9	6.4	6.6	6.2	5.9	5.5	5.8
5-10	*	5.1	6.65	-	6.7	-	-	-	6.6	-	-	-	-
10-30	*	6.15	5.0	-	7.1	-	-	-	-	-	-	-	-

*assumed same as control

(continued)

TABLE E-3. (continued)

Depth (cm)	Days 71	77	84	91	100	105	113	124	133	141	152	159	166
Control													
0-5	7.1	6.95	8.7	7.4	7.5	7.3	7.0	7.0	7.1	7.5	7.6	7.6	7.55
5-10	7.4	6.8	8.0	7.4	7.1	6.9	6.45	6.6	7.1	7.65	7.4	7.8	7.2
10-30	-	-	-	-	-	-	-	-	-	-	-	-	-
T-1													
0-5	6.6	6.35	6.7	6.4	6.6	6.6	6.3	6.2	7.0	6.5	6.5	7.25	7.1
5-10	6.4	6.2	6.6	6.45	6.7	6.7	6.7	6.85	6.0	6.2	7.2	7.4	7.6
10-30	-	-	-	-	-	-	-	-	-	-	-	-	-
T-2													
0-5	6.2	6.2	7.1	5.3	6.8	5.0	5.5	6.5	7.3	6.9	7.6	7.9	8.1
5-10	6.45	6.7	8.2	6.1	7.5	5.6	6.6	6.7	7.5	8.0	6.7	8.0	8.2
10-30	-	-	-	-	-	-	-	-	-	-	-	-	-

(continued)

TABLE E-3 (continued)

Depth (cm)	Days	
	174	181
Control		
0-5	7.5	7.6
5-10	7.4	6.9
10-30	-	-
T-1		
0-5	7.9	6.9
5-10	6.7	7.2
10-30	-	-
T-2		
0-5	8.2	7.4
5-10	8.0	7.5
10-30	-	-

TABLE E-4. pH OF CLAY SOILS - ANILINE SPILL

Depth (cm)	Pre-Aniline Sample -2	Days 1	2	5	7	14	15	17	34	37	43	50	57
Control													
0-5	6.6	6.4	6.15	3.2	10.0	10.0	9.2	8.1	7.1	7.2	7.0	6.85	6.9
5-10	6.4	5.75	5.45	-	5.5	-	-	-	6.8	-	-	-	-
10-30	6.7	5.2	6.7	-	5.15	-	-	-	-	-	-	-	-
T-1													
0-5	*	6.1	5.7	9.6	5.65	5.8	6.0	5.5	5.9	5.5	5.65	5.5	5.75
5-10	*	5.6	5.8	-	5.7	-	-	-	5.9	-	-	-	-
10-30	*	5.2	5.7	-	5.9	-	-	-	-	-	-	-	-
T-2													
0-5	*	6.65	5.9	4.2	6.7	5.8	5.8	5.7	7.5	6.7	5.2	6.0	6.4
5-10	*	5.3	5.7	-	6.15	-	-	-	6.4	-	-	-	-
10-30	*	5.5	6.1	-	5.1	-	-	-	-	-	-	-	-

*assumed same as control

(continued)

TABLE E-4. (continued)

Depth (cm)	Days												
	71	77	84	91	100	105	113	124	133	141	152	159	166
Control													
0-5	7.7	7.8	10.9	9.9	9.7	10.5	6.65	9.4	10.4	7.5	7.4	6.7	10.1
5-10	6.4	6.4	8.3	8.5	6.3	9.8	5.6	9.3	8.7	7.0	5.6	6.4	8.6
10-30	-	-	-	-	-	-	-	-	-	-	-	-	-
T-1													
0-5	5.7	5.6	7.1	6.3	6.0	5.6	5.5	5.6	6.0	5.9	5.7	7.6	6.2
5-10	5.75	5.7	6.9	6.2	5.4	6.3	5.6	6.15	5.6	5.9	6.1	6.25	5.6
10-30	-	-	-	-	-	-	-	-	-	-	-	-	-
T-2													
0-5	6.55	6.3	6.3	6.3	6.9	6.95	7.3	7.25	6.9	7.2	6.5	7.5	6.7
5-10	5.0	6.85	5.4	5.95	6.6	6.95	6.2	6.95	6.7	7.5	6.7	7.2	5.4

(continued)

TABLE E-4. (continued)

Depth (cm)	Days	
	174	181
Control		
0-5	9.4	10.1
5-10	7.6	8.6
10-30	-	-
T-1		
0-5	6.5	7.0
5-10	6.65	-
10-30	-	-
T-2		
0-5	7.6	6.9
5-10	6.7	7.7
10-30	-	-

TABLE E-5. PERCENT MOISTURE IN ORGANIC SOILS - ANILINE SPILL

Depth (cm)	Pre-Aniline Sample -2	Days 1	2	5	7	14	15	34	37	43	50	57	71
Control													
0-5	24.27	26.65	25.15	28.86	27.14	37.02	39.61	34.69	41.18	33.59	24.0	29.36	27.27
5-10	22.42	25.10	28.48	-	20.03	-	-	19.06	-	-	-	-	21.32
10-30	27.62	20.71	21.41	-	20.99	-	-	-	-	-	-	-	-
T-1													
0-5	*	29.56	29.61	24.95	22.03	42.66	44.17	37.77	33.94	30.06	31.61	30.21	33.86
5-10	*	22.88	20.18	-	11.01	-	-	25.38	-	-	-	-	30.80
10-30	*	19.68	22.88	-	9.0	-	-	-	-	-	-	-	-
T-2													
0-5	*	41.04	27.95	35.69	33.86	37.52	38.56	35.36	32.02	34.59	35.03	34.57	33.47
5-10	*	20.48	18.45	-	8.23	-	-	23.45	-	-	-	-	17.62
10-30	*	18.45	21.32	-	8.07	-	-	-	-	-	-	-	-

*assumed same as control

(continued)

TABLE E-5. (continued)

Depth (cm)	Days 77	84	91	100	105	113	124	133	141	152	159	166
Control												
0-5	23.62	27.74	30.17	39.22	25.28	35.19	26.66	42.83	27.22	30.65	30.10	31.23
5-10	17.26	17.47	18.62	19.40	19.53	26.15	21.04	25.52	31.57	28.66	24.81	20.79
10-30	-	-	-	-	-	-	-	-	-	-	-	-
T-1												
0-5	31.00	22.47	36.39	39.33	35.98	31.50	31.64	35.74	39.96	36.07	32.13	32.81
5-10	22.51	21.58	29.26	29.91	22.60	24.38	26.71	24.37	27.06	30.22	31.67	33.87
10-30	-	-	-	-	-	-	-	-	-	-	-	-
T-2												
0-5	32.75	29.03	23.23	29.35	38.32	27.92	21.24	25.01	32.06	30.53	32.67	33.67
5-10	23.82	24.06	22.06	18.36	21.73	25.62	24.37	21.18	22.51	24.29	28.59	24.98
10-30	-	-	-	-	-	-	-	-	-	-	-	-

(continued)

TABLE E-5. (continued)

Depth (cm)	Days	
	174	181
Control		
0-5	33.00	26.48
5-10	23.10	20.68
10-30	-	-
T-1		
0-5	34.34	31.07
5-10	29.96	23.02
10-30	-	-
T-2		
0-5	47.82	23.80
5-10	53.93	34.69
10-30	-	-

TABLE E-6. PERCENT MOISTURE IN SANDY SOILS - ANILINE SPILL

Depth (cm)	Pre-Aniline Sample -2	Days											
		1	2	5	7	14	15	34	37	43	50	57	71
Control													
0-5	18.23	28.60	26.72	25.18	8.38	25.36	25.09	25.65	24.33	24.02	25.25	23.15	22.50
5-10	19.12	26.29	25.69	-	6.54	-	-	23.68	-	-	-	-	22.63
10-30	22.81	26.52	25.99	-	8.46	-	-	-	-	-	-	-	-
T-1													
0-5	*	22.78	24.29	22.00	5.71	24.98	24.12	23.61	22.79	31.03	25.62	22.27	34.78
5-10	*	19.01	21.84	-	6.02	-	-	20.75	-	-	-	-	18.32
10-30	*	21.84	21.34	-	7.11	-	-	-	-	-	-	-	-
T-2													
0-5	*	23.29	27.04	20.69	6.73	23.14	29.74	26.50	26.80	28.07	25.33	26.27	27.65
5-10	*	20.00	-	-	6.13	-	-	23.65	-	-	-	-	18.62
10-30	*	27.05	23.48	-	9.5	-	-	-	-	-	-	-	-

*assumed same as control

(continued)

TABLE E-6 (continued)

Depth (cm)	Days 77	84	91	100	105	113	124	133	141	152	159	166
Control												
0-5	21.86	19.27	23.75	23.36	21.67	20.89	21.19	21.33	21.12	20.79	19.69	21.93
5-10	21.38	41.10	6.64	20.21	20.27	21.04	20.33	23.81	17.42	21.83	21.37	23.23
10-30	-	-	-	-	-	-	-	-	-	-	-	-
T-1												
0-5	21.80	18.96	20.80	20.13	26.35	19.93	22.31	19.22	22.96	20.68	25.05	-
5-10	18.34	19.20	18.13	19.55	21.03	19.91	28.66	19.16	19.77	20.00	20.74	23.34
10-30	-	-	-	-	-	-	-	-	-	-	-	-
T-2												
0-5	26.36	22.77	21.45	24.75	22.58	24.53	25.98	21.25	20.23	21.58	21.21	21.50
5-10	21.24	21.25	19.35	20.70	16.43	22.17	18.18	27.78	16.94	21.12	21.64	21.09
10-30	-	-	-	-	-	-	-	-	-	-	-	-

(continued)

TABLE E-6. (continued)

Depth (cm)	Days	
	174	181
Control		
0-5	23.59	18.41
5-10	16.86	28.81
10-30	-	-
T-1		
0-5	26.97	20.59
5-10	22.38	22.67
10-30	-	-
T-2		
0-5	21.92	23.66
5-10	22.46	23.95
10-30	-	-

TABLE E-7. PERCENT MOISTURE IN CLAY SOILS - ANILINE SPILL

Depth (cm)	Pre-Aniline Sample					Days							
	-2	1	2	5	7	14	15	34	37	43	50	57	71
Control													
0-5	15.74	10.64	17.85	18.73	9.48	18.13	21.21	13.64	13.86	17.32	17.80	24.21	13.96
5-10	26.01	16.74	16.92	-	7.56	-	-	16.75	-	-	-	-	14.88
10-30	12.70	18.32	24.21	-	10.99	-	-	-	-	-	-	-	-
T-1													
0-5	*	18.44	28.52	15.83	5.23	15.04	15.38	15.63	13.83	20.0	17.53	16.35	11.67
5-10	*	18.16	17.36	-	10.15	-	-	15.83	-	-	-	-	12.22
10-30	*	18.08	17.73	-	4.87	-	-	-	-	-	-	-	-
T-2													
0-5	*	18.10	17.11	19.45	9.57	24.84	25.39	19.92	16.43	22.85	21.67	19.52	17.71
5-10	*	18.52	16.19	-	8.23	-	-	17.88	-	-	-	-	15.68
10-30	*	16.87	19.32	-	6.4	-	-	-	-	-	-	-	-

*assumed same as control

(continued)

TABLE E-7. (continued)

Depth (cm)	Days											
	77	84	91	100	105	113	124	133	141	152	159	166
Control												
0-5	18.03	16.42	15.45	16.94	16.29	14.43	12.33	13.98	13.09	12.84	19.78	21.73
5-10	14.35	15.81	-	15.17	17.32	13.37	16.08	17.54	13.63	10.70	16.16	15.42
10-30	-	-	-	-	-	-	-	-	-	-	-	-
T-1												
0-5	68.72	9.90	11.72	10.94	10.62	12.62	9.25	17.58	-	9.22	-	18.02
5-10	21.51	12.17	13.02	14.37	13.54	11.71	10.93	11.61	21.17	11.28	14.45	11.88
10-30	-	-	-	-	-	-	-	-	-	-	-	-
T-2												
0-5	15.05	16.84	16.54	14.27	15.00	15.28	-	12.87	13.11	12.01	13.93	12.33
5-10	15.26	16.09	0.76	23.86	14.40	14.18	38.95	14.16	13.04	14.96	15.55	16.57
10-30	-	-	-	-	-	-	-	-	-	-	-	-

(continued)

TABLE E-7. (continued)

Depth (cm)	Days	
	174	181
Control		
0-5	15.80	-
5-10	16.25	18.53
10-30	-	-
T-1		
0-5	10.75	12.87
5-10	13.38	-
10-30	-	-
T-2		
0-5	13.24	10.54
5-10	13.22	13.72
10-30	-	-

TABLE E-8. ANILINE LEVELS - MIDDLE SOIL LAYERS (5-10 cm)

Aniline Middle Levels	1	2	5	28	34	37	43	50	57	71
ORGANIC										
Control	1533	431	3808	2779	66	3567	549	1419	2013	1607
T-1	460	752	779	13	43	8198	22	263	5223	3081
T-2	894	135	2138	6045	89	4320	152	975	2728	1816
Control	5715	1696	8850	13123	4332	9328	8876	4473	3470	2949
T-1	2255	1227	3822	7612	2395	7058	11438	7896	10555	10825
T-1	565	99	3771	10144	13556	6576	8365	4352	5066	7590
Control	324	1078	4385	2018	3785	2526	2895	2541	1157	4290
T-1	1081	959	1429	524	3156	2128	1339	1229	955	3525
T-2	587	1041	1314	1696	32	4609	1317	3165	2304	1799

(continued)

TABLE E-8 (continued)

Aniline Middle Levels	77	84	100	105	133	141	152	159	166	181
Control	203	57	2176	1	115	49	6520	218	70	23
T-1	327	100	1045	1	484	2829	1	98	45	14
T-2	541	2074	719	823	961	1168	353	81	1510	854
Control	9611	3099	3107	5404	-	3264	2567	68	331	2465
T-1	14143	2263	2637	4507	1434	3261	2162	1887	177	130
T-2	8270	1376	2909	7712	3434	2665	65	1847	232	2605
Control	10450	1406	2098	2284	2263	2958	3352	3111	1778	1285
T-1	3332	1045	3	1	1650	897	1632	558	1465	60
T-2	3499	695	1193	2686	2955	1270	1712	1857	2995	712

APPENDIX F

CHLORDANE DATA

This appendix contains additional supplemental data obtained on land restoration techniques for the chlordane spill. The following data are included in this Appendix.

- background soil analyses
- pH of soils as a function of core depth and time
- percent moisture of soils as a function of core depth and time

TABLE F-1. BACKGROUND ANALYSES OF SOILS - CHLORDANE SPILL

Property Measure	Depth (cm)	Organic Soil	Sandy Soil	Clay Soil
pH	0-5	6.9	6.3	5.2
	5-10	7.2	7.5	4.5
	10-30	7.2	8.1	5.2
% Moisture	0-5	32.5	22.1	16.7
	5-10	24.2	23.2	13.5
	10-30	20.6	25.2	15.5
Total Phosphorous (ppm)	0-5	60	13	19
Potassium (ppm)	0-5	55	139	45
Calcium (ppm)	0-5	624	1200	708
Magnesium (ppm)	0-5	57	120	107

TABLE F-2. TOP LEVEL SOIL pH VALUES--CHLORDANE

		Days								
Soil Type	Soil Treatment	1	2	6	13	21	27	33	37	49
Organic	Control	7.5	7.4	7.4	7.5	7.5	7.4	7.4	7.5	6.8
	T-1	7.7	7.4	7.8	7.6	7.4	8.3	7.9	8.0	7.7
	T-2	7.0	7.0	7.1	7.3	7.3	7.4	8.2	9.2	8.6
Sandy	Control	6.6	7.1	6.8	6.8	6.7	7.3	6.7	6.9	7.1
	T-1	8.5	9.4	7.5	7.6	7.0	9.0	8.6	8.5	8.3
	T-2	6.6	6.7	7.4	7.3	7.5	7.1	8.6	8.7	8.6
Clay	Control	9.6	10.0	10.3	8.5	10.0	9.8	9.7	9.4	9.0
	T-1	5.1	6.0	5.8	5.6	5.3	5.1	5.2	5.5	6.3
	T-2	6.4	5.4	7.3	8.3	7.4	7.3	9.1	8.9	8.8

TABLE F-3. TOP LEVEL PERCENT MOISTURE LEVELS--CHLORDANE

		Days								
Soil Type	Soil Treatment	1	2	6	13	21	27	33	37	49
Organic	Control	33.9	31.1	32.7	33.1	32.5	32.1	28.7	28.8	27.4
	T-1	35.2	30.4	34.2	30.9	25.2	30.9	31.0	31.9	23.9
	T-2	19.4	21.3	11.5	14.5	19.4	24.6	23.3	21.3	14.5
Sandy	Control	25.4	22.9	21.6	23.2	27.1	23.4	22.5	21.6	22.4
	T-1	25.0	24.7	30.3	19.8	16.9	26.1	24.2	21.3	15.7
	T-2	12.7	25.1	21.9	24.7	23.9	24.5	24.3	26.7	28.2
Clay	Control	16.9	16.7	17.8	13.0	10.4	11.5	13.1	12.0	11.5
	T-1	16.6	18.9	16.8	28.9	12.5	13.3	15.4	16.2	15.2
	T-2	18.0	15.7	24.6	30.5	15.8	12.5	17.7	15.2	10.8

EPA Form 2350-4 (4-80)
(PREVIOUSLY EPA FORM 261)
TYPING GUIDE SHEET

TABLE F-4. SOIL BACTERIAL POPULATION-CHLORDANE SPILL

Soil Type	Treatment	Initial	Days 1	6	13	21
Organic	Control	3.6×10^{7}	3.6×10^{7}	2.5×10^{8}	3.3×10^{8}	4.7×10^{8}
	T-1	*	6.3×10^{6}	2.7×10^{9}	4.8×10^{8}	2.3×10^{9}
	T-2	*	1.0×10^{8}	3.2×10^{8}	2.7×10^{8}	1.5×10^{8}
Sandy	Control	1.8×10^{7}	3.2×10^{7}	4.8×10^{8}	2.2×10^{8}	3.0×10^{8}
	T-1	*	3.9×10^{7}	1.2×10^{9}	4.5×10^{8}	2.0×10^{8}
	T-2	*	3.1×10^{6}	2.8×10^{8}	--	2.2×10^{8}
Clay	Control	3.9×10^{6}	4.2×10^{6}	9.0×10^{6}	7.1×10^{7}	1.3×10^{8}
	T-1	*	1.7×10^{7}	1.0×10^{8}	1.4×10^{8}	1.7×10^{8}
	T-2	*	1.5×10^{7}	2.9×10^{8}	2.5×10^{8}	4.5×10^{7}

* Assumed same as control.

APPENDIX G

2,4-DINITROPHENOL DATA

This Appendix contains additional supplemental data obtained on land restoration techniques for the 2,4-dinitrophenol spill. The following data are included in this appendix.

- background soil analyses
- pH of soils as a function of core depth and time
- percent moisture of soils as a function of core depth and time

TABLE G-1. BACKGROUND ANALYSES OF SOILS--DINITROPHENOL SPILL

Property Measured	Depth (Ccm)	Organic Soil	Sandy Soil	Clay Soil
pH	0-5	6.8	5.6	6.7
	5-10	6.0	4.6	6.7
	10-30	4.6	4.9	6.0
% Organic Matter	0-5	31	23.1	15
	5-10	22	20	11
	10-30	19	21	13
Total Phosphorus (ppm)	(0-5)	60	13	19
Potassium (ppm)	(0-5)	55	139	45
Calcium (ppm)	(0-5)	624	1200	708
Magnesium (ppm)	(0-5)	57	120	107

TABLE G-2. TOP LEVEL SOIL pH VALUES--DINITROPHENOL

		Days						
Soil Type	Treatment	1	2	12	19	23	34	40
Organic	Control	7.3	7.2	6.7	7.0	5.4	7.1	7.2
	Treated	6.4	6.0	6.4	9.0	7.8	8.1	8.7
Sandy	Control	5.1	6.2	5.3	5.6	5.3	6.6	5.0
	Treated	5.0	6.2	7.2	8.7	8.0	7.3	9.3
Clay	Control	5.8	6.2	4.5	6.1	4.7	7.3	5.8
	Treated	5.9	4.7	7.4	9.0	7.7	7.5	8.5

TABLE G-3. TOP LEVEL PERCENT MOISTURE VALUES--DINITROPHENOL

		Days					
Soil Type	Treatment	1	2	12	19	23	40
Organic	Control	32.7	27.0	28.4	22.9	26.3	19.7
	Treated	34.0	34.1	32.7	34.1	30.5	33.7
Sandy	Control	25.0	31.6	24.2	22.6	23.7	13.5
	Treated	27.8	26.1	27.2	25.1	18.9	25.2
Clay	Control	28.6	18.1	15.4	11.4	20.7	7.8
	Treated	15.5	16.1	19.6	17.3	16.0	8.8

TABLE G-4. SOIL BACTERIAL POPULATIONS - DINITROPHENOL SPILL

Soil Type		Days		
treatment	initial	1	12	40
Organic				
Control	1.6×10^{8}	6.0×10^{7}	6.8×10^{7}	2.1×10^{7}
Treated	*	3.1×0^{7}	3.6×10^{6}	1.8×10^{7}
Sandy				
Control	6.7×10^{8}	2.7×10^{6}	1.4×10^{7}	9.3×10^{5}
Treated	*	9.9×10^{6}	1.7×10^{7}	3.2×10^{6}
Clay				
Control	8.9×10^{7}	5.1×10^{7}	1.1×10^{6}	1.5×10^{6}
Treated	*	3.3×10^{7}	7.9×10^{7}	6.3×10^{5}

APPENDIX H

CADMIUM NITRATE AND LEAD NITRATE DATA

This Appendix contains additional supplemental data obtained on land restoration techniques for cadmium nitrate and lead nitrate spills. The following data are included in this Appendix.

- pH of soil

TABLE H-1. SOIL pH LEVELS IN CADMIUM UPTAKE STUDY

Soil Type	Treatment	Days 1	2	3	13	15	23	53	68	106
Organic	control	5.5	6.5	6.7	8.2	7.3	7.4	7.2	6.8	6.7
	pH(w) lettuce & chard	5.5	6.5	7.7	7.2	7.5	7.1	7.1	7.1	7.4
	chelated & pH	6.3	6.9	6.6	7.4	7.1	6.9	7.3	7.2	6.8
	pH(w) grass	6.1	6.3	6.4	7.2	7.1	7.6	6.6	6.5	7.2
Sandy	control	6.1	6.4	6.4	5.0	4.8	5.6	6.6	6.3	5.5
	pH(w) lettuce & chard	5.0	5.5	6.4	5.9	6.7	4.5	6.5	7.1	7.0
	chelated & pH	4.8	6.7	5.2	5.8	5.0	5.7	6.5	7.1	6.6
	pH(w) grass	6.2	6.5	6.2	4.7	5.4	6.3	6.3	7.2	6.4
Clay	control	5.3	4.8	5.0	4.4	5.4	6.5	7.7	7.8	7.6
	pH(w) lettuce & chard	7.0	6.7	7.1	7.6	7.9	7.2	8.0	7.9	7.0
	chelated & pH	6.5	6.6	6.4	6.6	7.3	5.3	7.7	7.5	7.1
	pH(w) grass	5.3	6.1	5.8	5.2	5.6	6.9	7.9	7.6	6.8

TABLE H-2. SOIL pH LEVELS IN LEAD UPTAKE STUDY

Soil Type	Treatment	Days 1	3	13	15	23	53	68	106
Organic	Control	5.9	7.5	7.7	7.2	7.5	7.5	6.8	6.8
	pH(w) lettuce & chard	6.1	6.7	6.8	6.9	7.5	6.8	6.9	7.2
	Chelated & pH	7.1	7.7	6.9	6.9	7.1	7.5	6.3	7.2
	pH(w) grass	6.3	6.6	6.9	6.9	7.2	7.0	6.3	6.5
Sandy	Control	5.6	5.2	4.7	4.7	4.8	5.8	6.8	7.4
	pH(w) lettuce & chard	5.9	6.4	6.0	6.3	6.4	7.0	7.2	6.0
	Chelated & pH	4.4	6.4	5.2	6.2	5.0	5.5	6.2	4.8
	pH(w) grass	5.5	6.2	6.0	5.1	4.9	6.4	7.1	5.9
Clay	Control	6.1	5.8	7.7	4.3	4.2	6.7	8.2	5.7
	pH(w) lettuce & chard	6.9	5.0	7.8	6.7	7.8	7.7	8.1	7.0
	Chelated & pH	6.4	7.1	7.9	4.9	6.6	7.5	7.6	6.8
	pH(w) grass	6.9	6.4	7.2	6.2	4.8	6.4	7.2	7.7